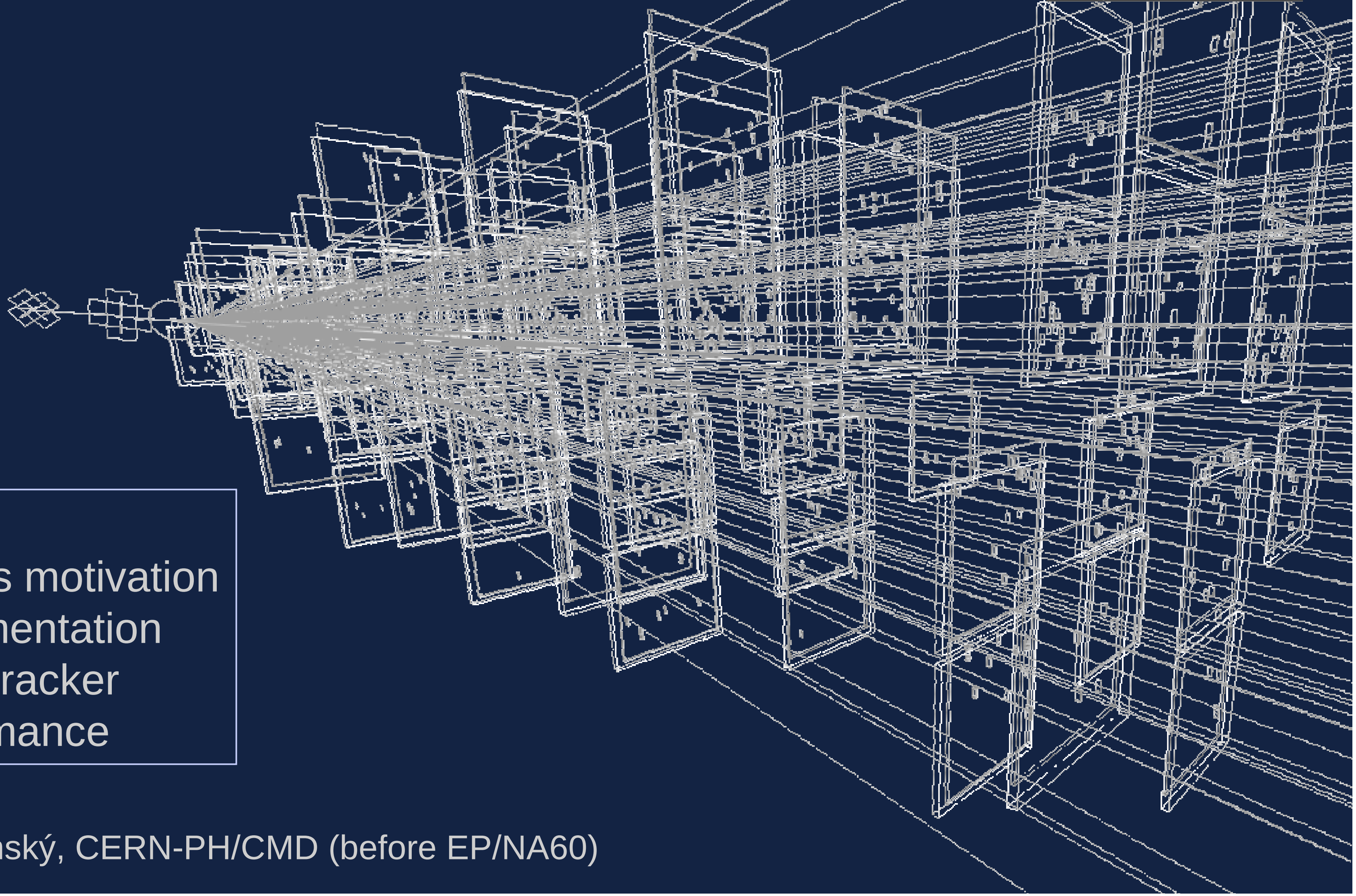
Experiment NA60

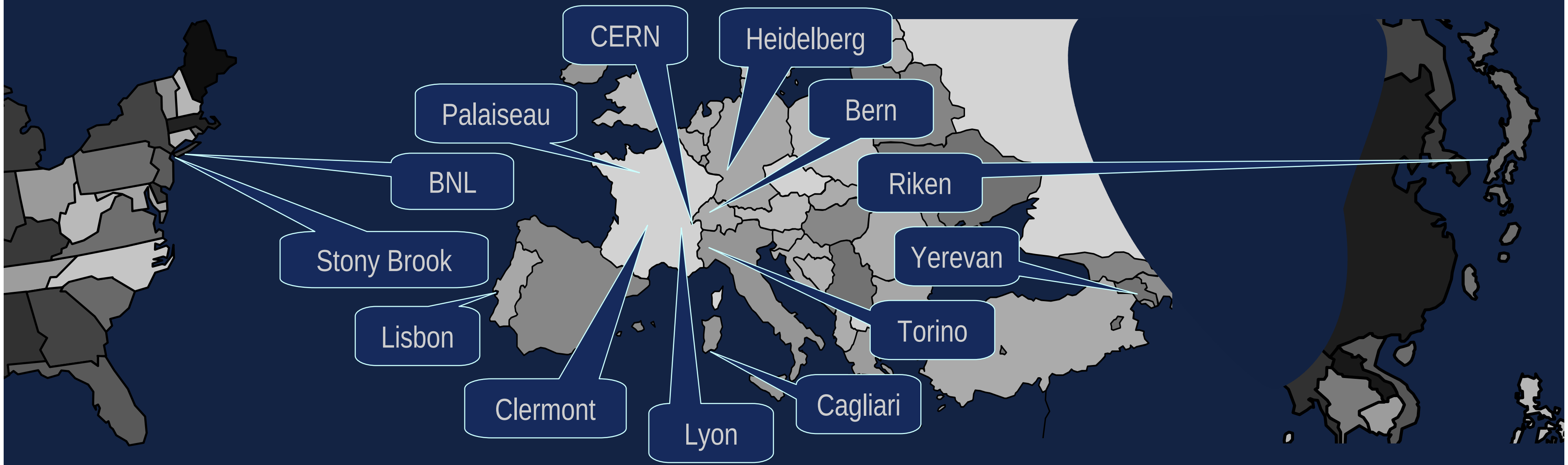


Outline:
- physics motivation
- instrumentation
- beam tracker
- performance

Peter Rosinský, CERN-PH/CMD (before EP/NA60)

Study of Prompt Dimuon and Charm Production with Proton and Heavy Ion Beams

R. Arnaldi, R. Averbeck, K. Banicz, K. Borer, J. Buytaert, J. Castor, B. Chaurand, W. Chen, B. Cheynis, C. Cicalò, A. Colla, P. Cortese, S. Damjanovic, A. David, A. de Falco, N. de Marco, A. Devaux, A. Drees, L. Ducroux, H. En'yo, A. Ferretti, M. Floris, P. Force, A. Grigorian, J.Y. Grossiord, N. Guettet, A. Guichard, H. Gulkanian, J. Heuser, M. Keil, L. Kluberg, Z. Li, C. Lourenço, J. Lozano, F. Manso, P. Martins, A. Masoni, A. Neves, H. Ohnishi, C. Oppedisano, P. Parracho, G. Puddu, E. Radermacher, P. Ramalhete, P. Rosinský, E. Scomparin, J. Seixas, S. Serci, R. Shahoyan, P. Sonderegger, H.J. Specht, R. Tieulent, G. Usai, H. Vardanyan, R. Veenhof, D. Walker and H. Wöhri

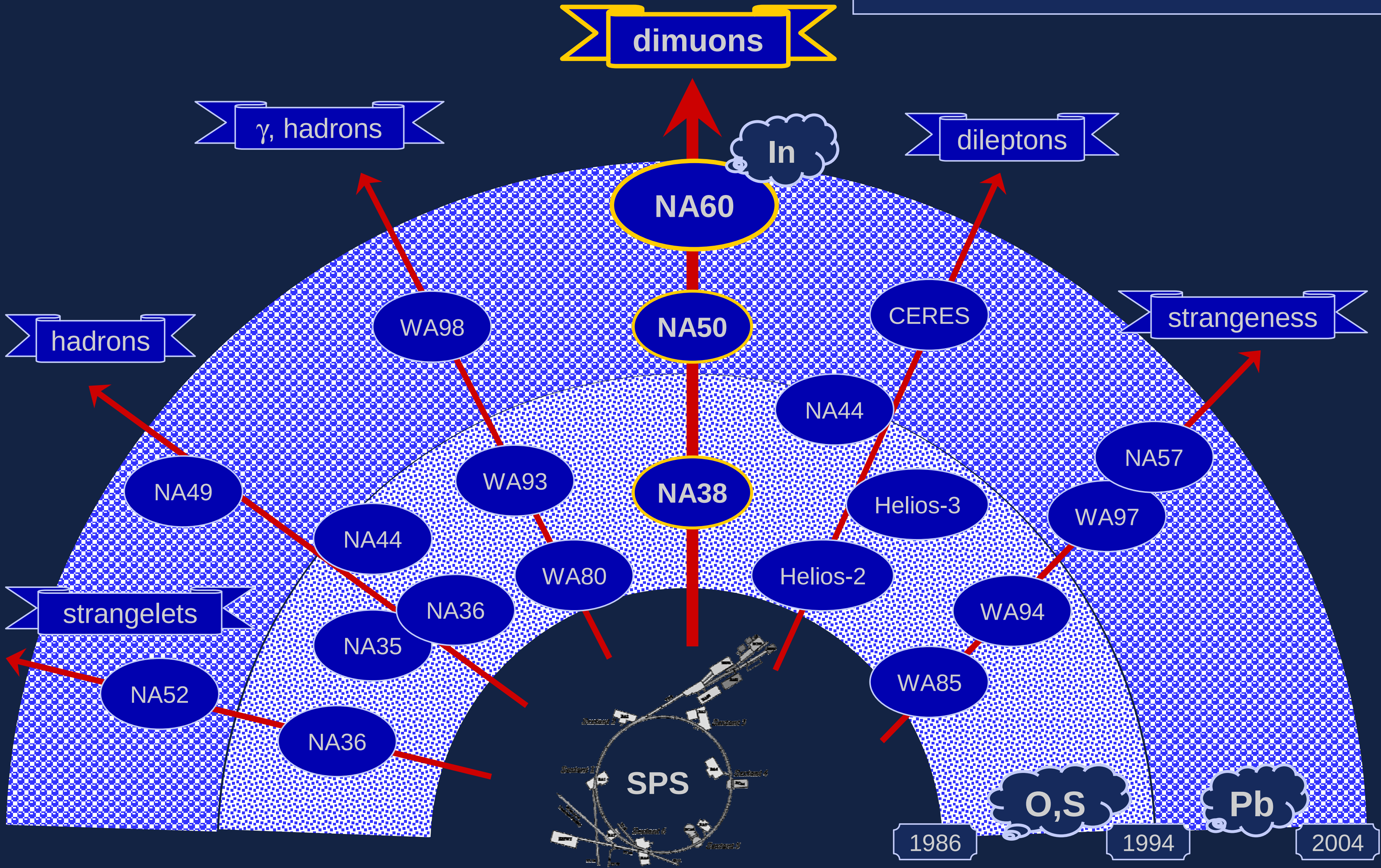


8 countries, 13 institutes, 57 people

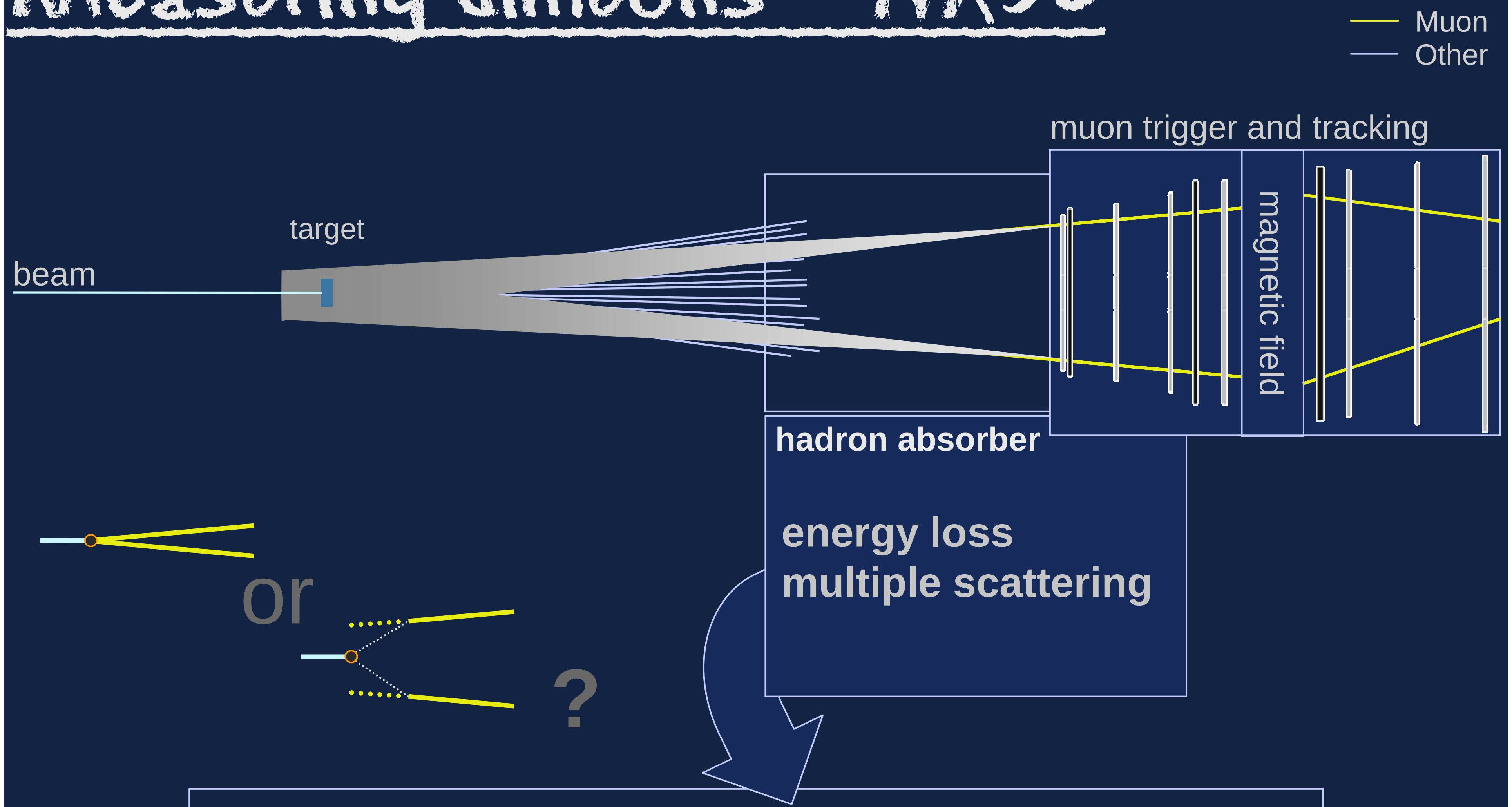
http://cern.ch/na60

Heavy ions at CERN

Lattice QCD calculations predict a phase transition into a deconfined state where chiral symmetry is restored.

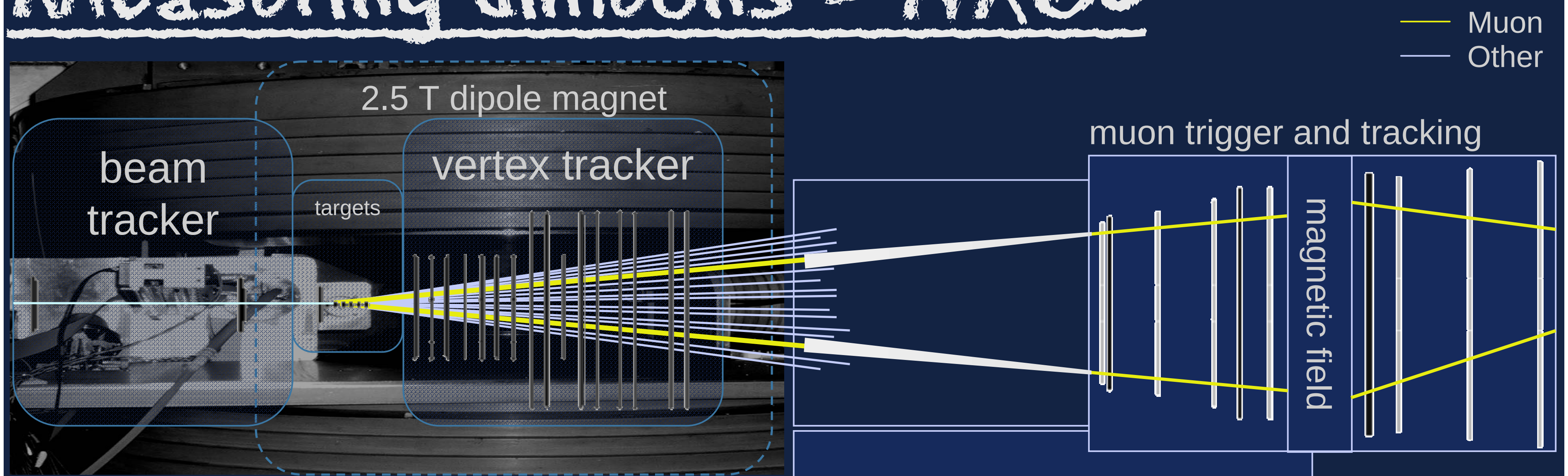


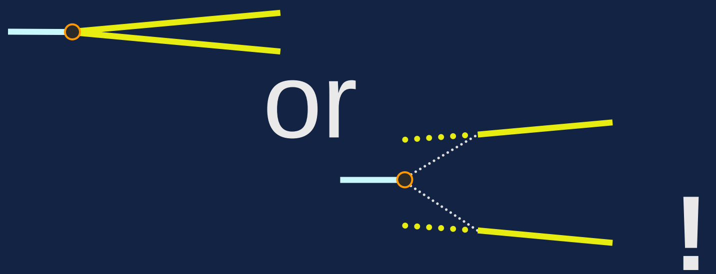
Measuring dimuons - NA50



- cannot distinguish **vertex muons** from **decay muons**
- **degraded** dimuon mass resolution

Measuring dimuons – NA60

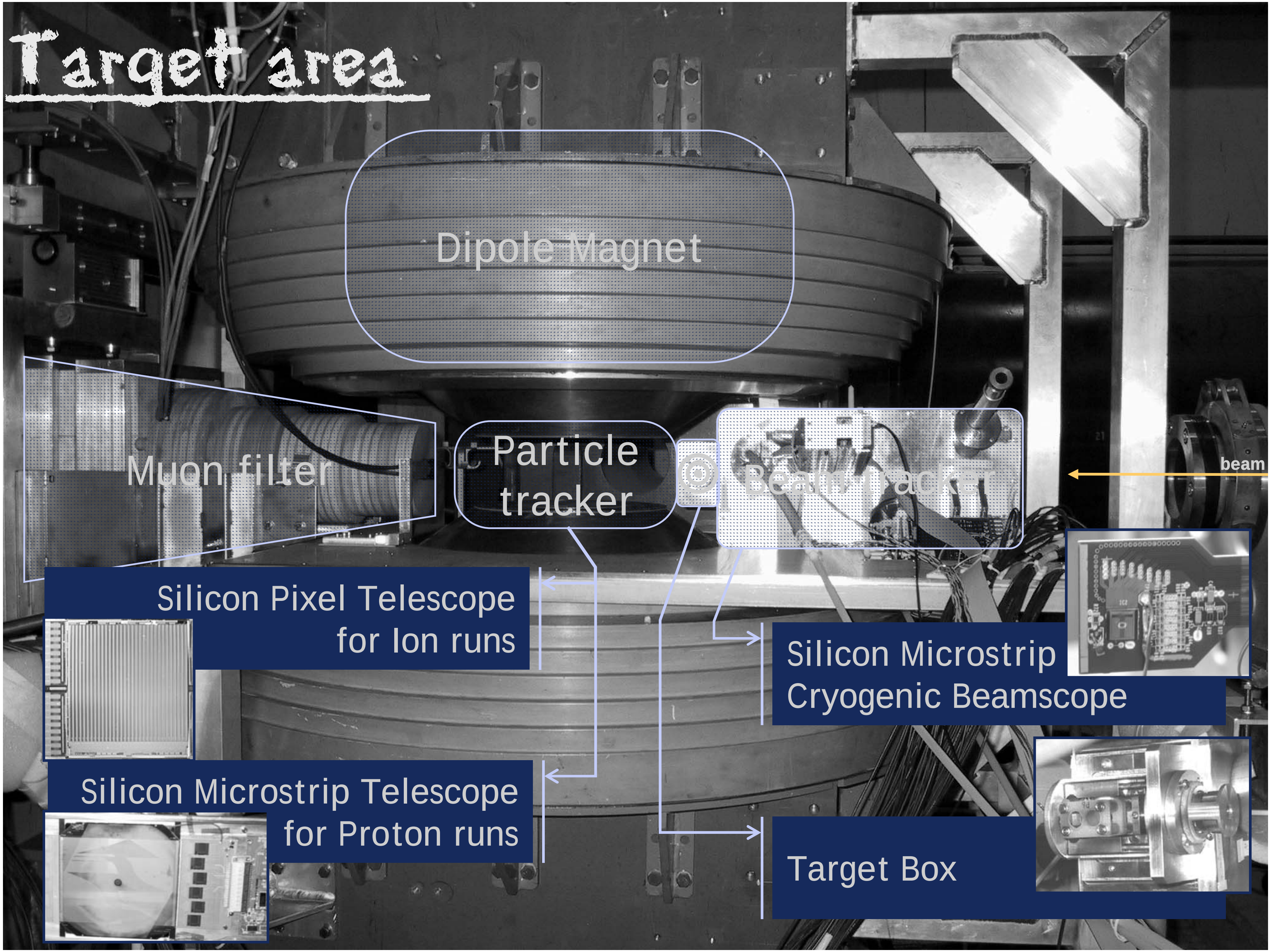




matching in **coordinate** and **momentum** space

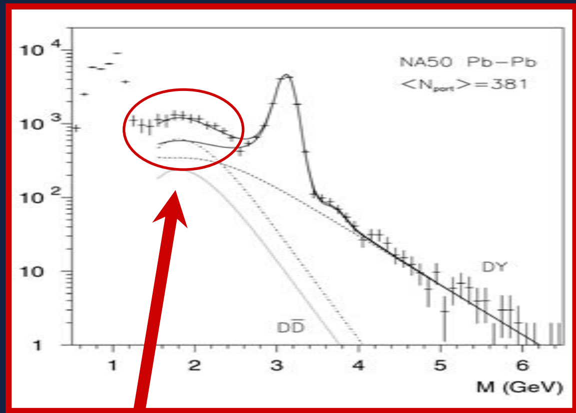
- **origin** of muons can be **accurately determined**
- **improved** dimuon mass resolution

Radiation tolerant tracker required!

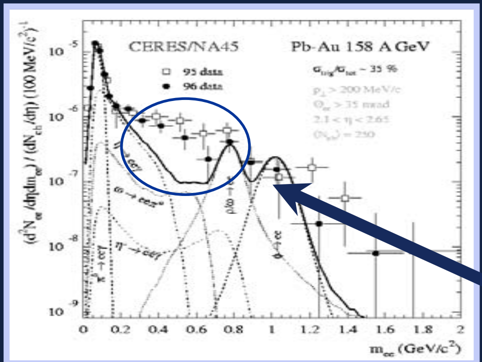

Target area
Dipole Magnet
Muon filter
Particle tracker
Beam tracker
beam
Silicon Pixel Telescope for Ion runs
Silicon Microstrip Cryogenic Beamscope
Silicon Microstrip Telescope for Proton runs
Target Box

Main physics topics

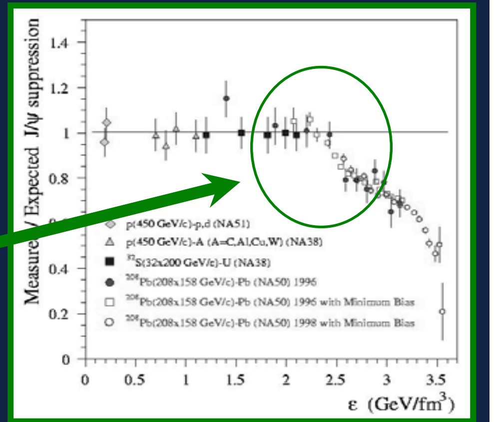
IMR – charm /thermal μμ

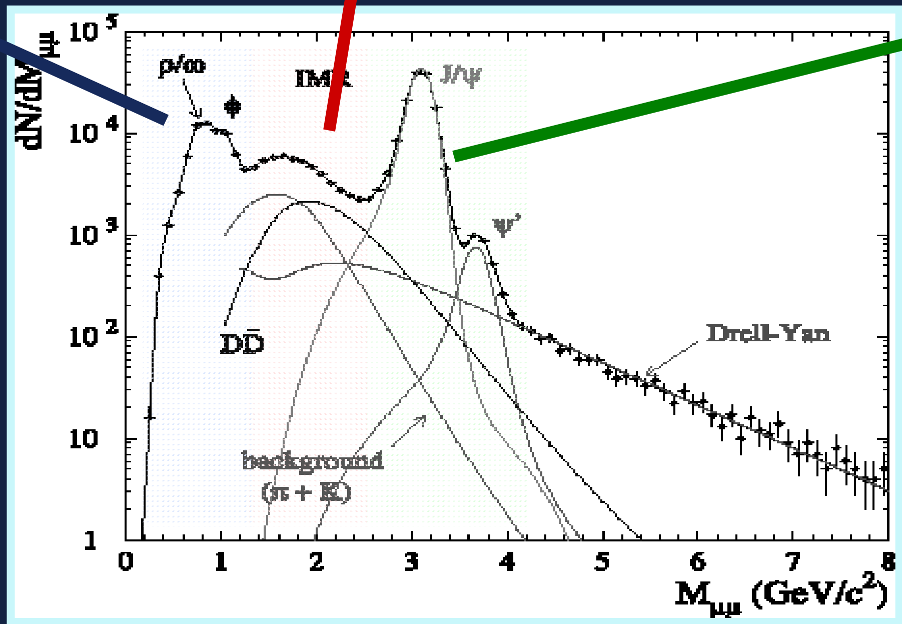


LMR – ω, ρ, φ production



J/ψ - deconfinement

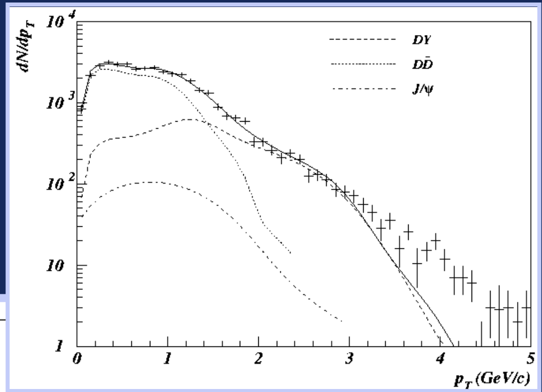


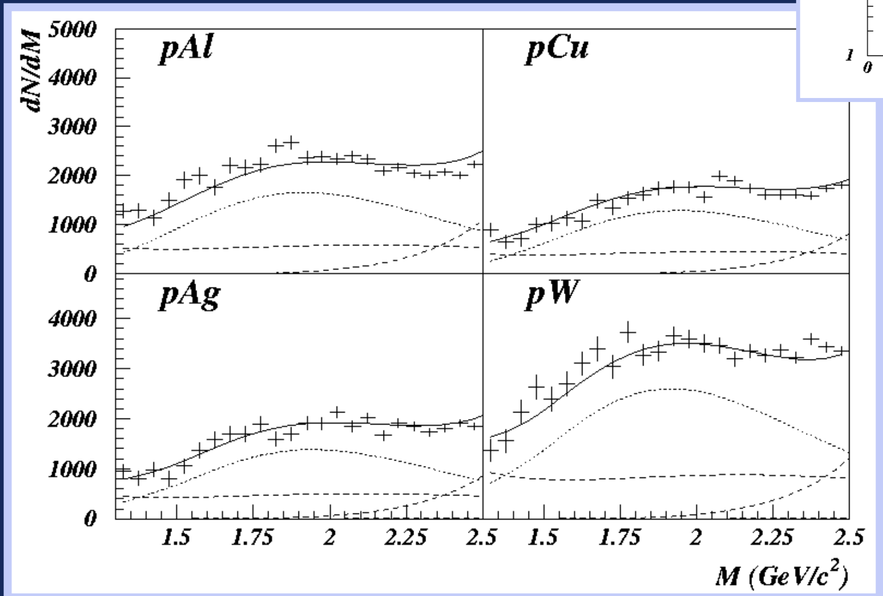


Intermediate mass region – protons

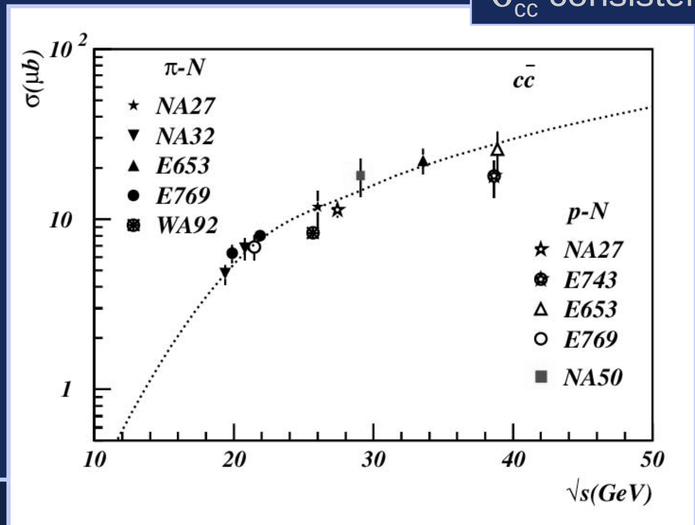
NA38/NA50: well understood

- sum of Drell-Yan, $D\bar{D}$, J/ψ
  - mass, p_t, rapidity, $\cos(\theta_{CS})$





σ$_{cc}$ consistent



Intermediate mass region – ions

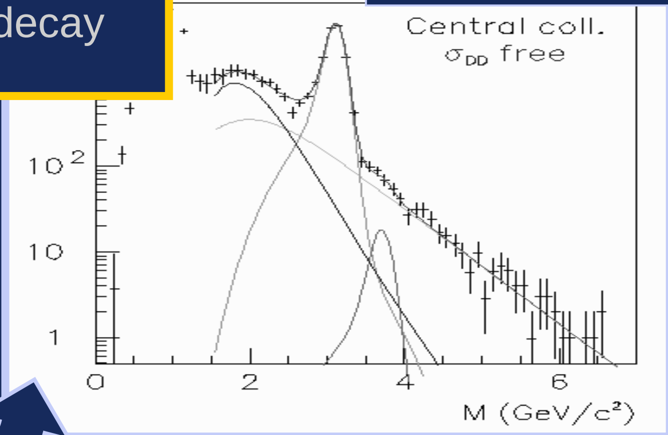
NA38/NA50: excess in Pb-Pb

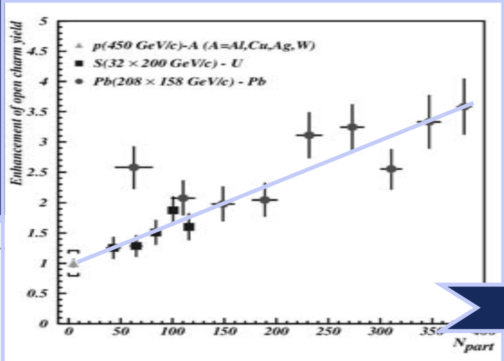
- ~3.5x for central collisions
- centrality dependence

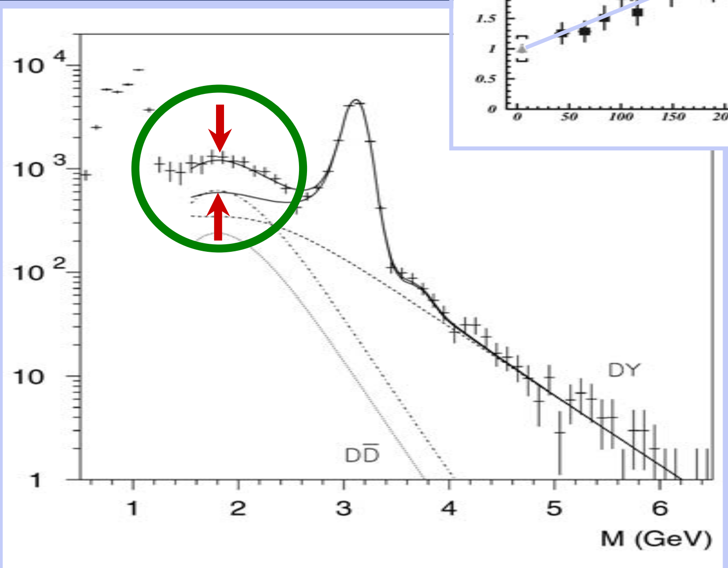
NA60: source of dimuons

- primary or secondary vertex
- prompt muons or D-decay

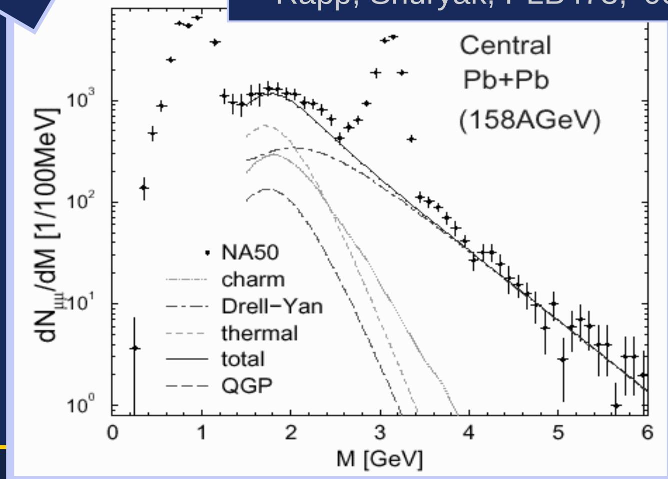
3x open charm ?
NA50 QM'99







thermal production ?
Rapp, Shuryak, PLB473, '00

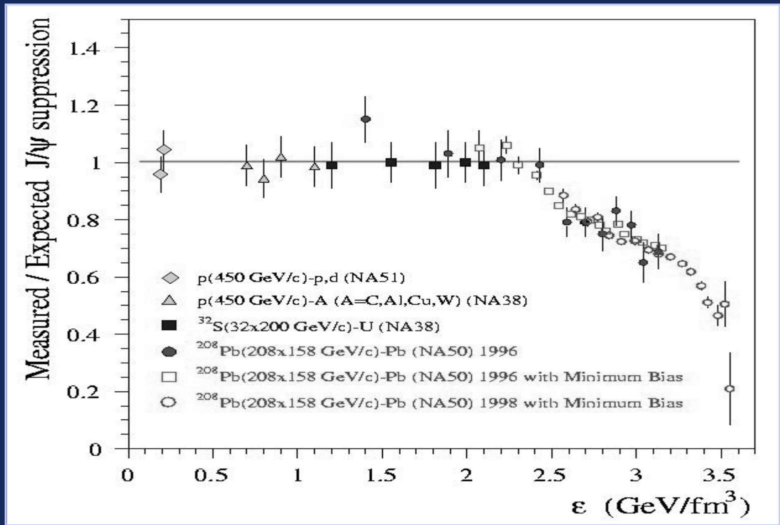


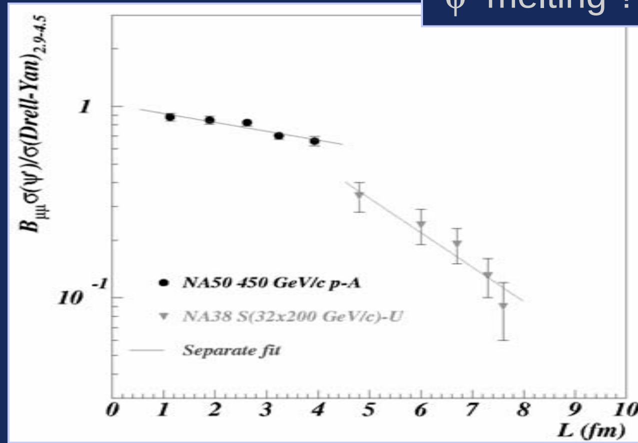
High mass region – ions

NA38/NA50

- Pb-Pb: anomalous J/ψ suppression
- increasing with centrality

ψ' melting ?

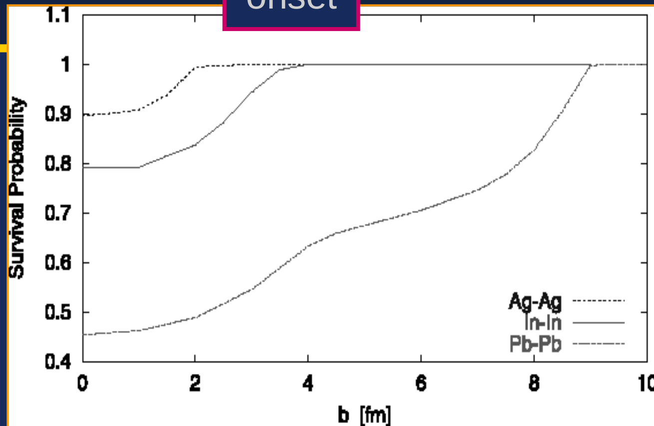




NA60

- lighter system, onset of suppression
  - In-In: b≈4 fm
- Which variable drives suppression ?
- ψ' production
- p-A: reference
  - A dependence of χ_c, impact on J/ψ

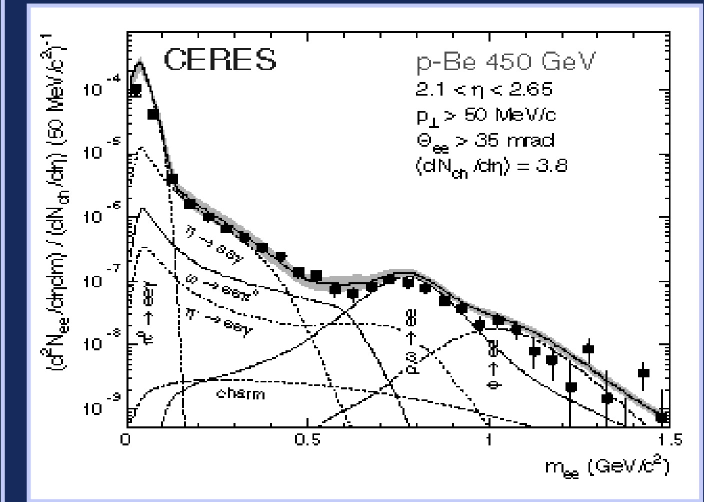
onset



Low mass region

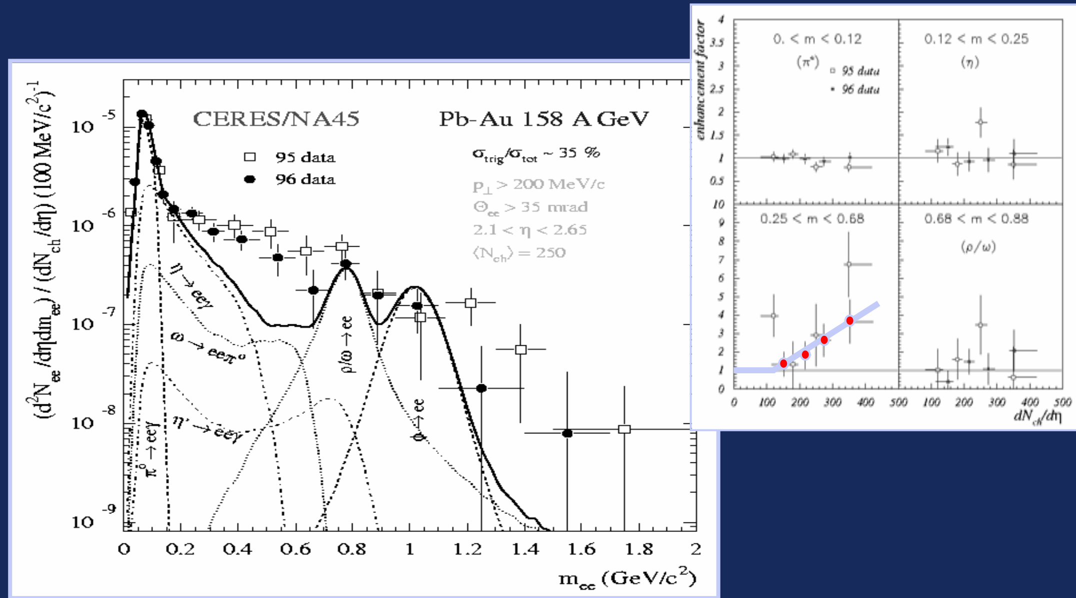
CERES: dielectrons

- p-A spectra understood
- sum of hadronic decays



CERES: excess in A-A

- 2.6x in 250–680 MeV, increase with N_{part}
- ρ meson modified by the nuclear medium ?
- chiral symmetry restoration ?

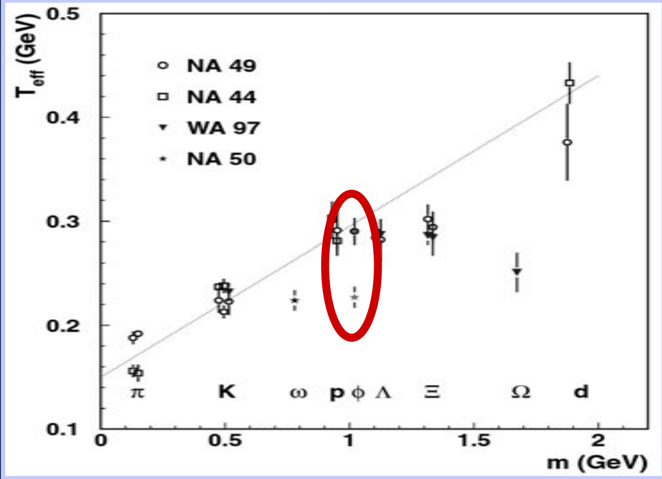


NA60

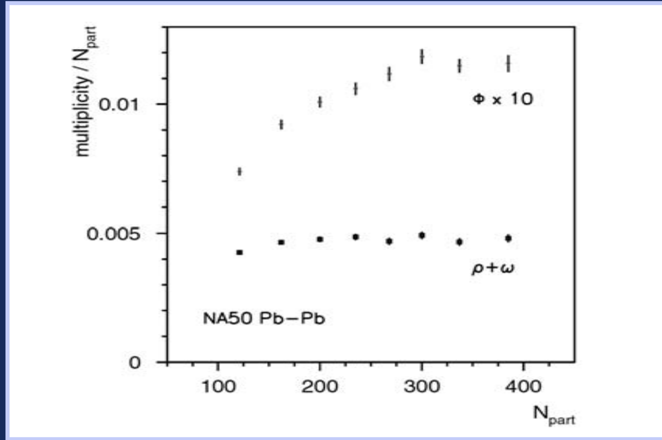
- better statistics
- better mass resolution (~20 MeV at ω)
- better signal/background
- m_t cut: >500 MeV, different systematic uncertainities

LMR – ϕ, prompt dimuons

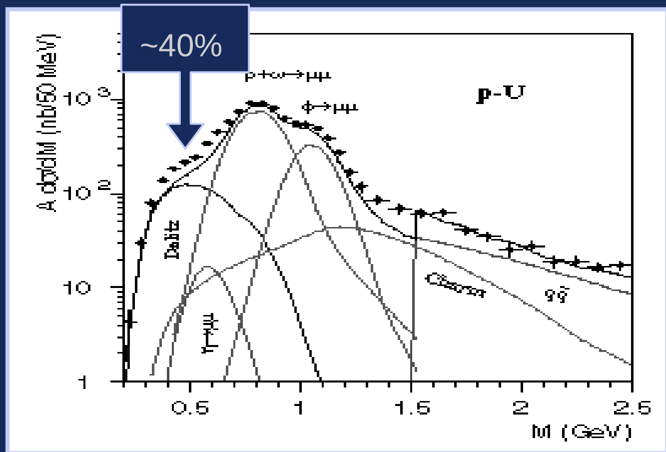
NA49-NA50:
- ϕ production in A-A: >3σ difference
  - different p_t window
  - KK vs. μμ decay



NA38/NA50: ϕ excess vs. ρ+ω in Pb-Pb



NA38: excess below ρ/ω in p-U



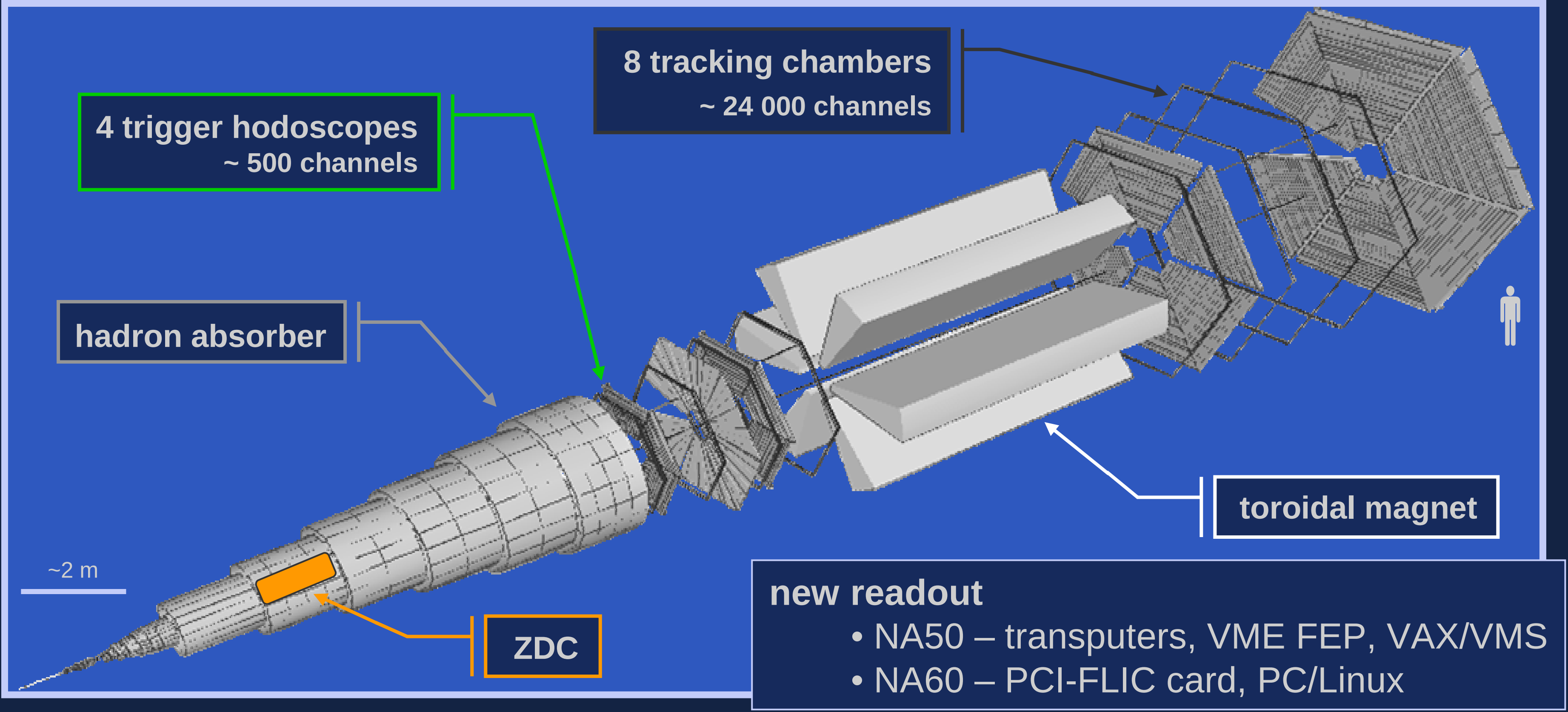
NA60:
- better mass resolution
- down to zero p_t
- p-A:
  - prompt: increase due to $q\bar{q}$?

Muon Spectrometer, ZDC

Muon Spectrometer: since 1978 (NA10/NA38/NA50/NA60)

- selective dimuon trigger (4 scintillation hodoscopes)
- dimuon tracking (8 multiwire proportional chambers)

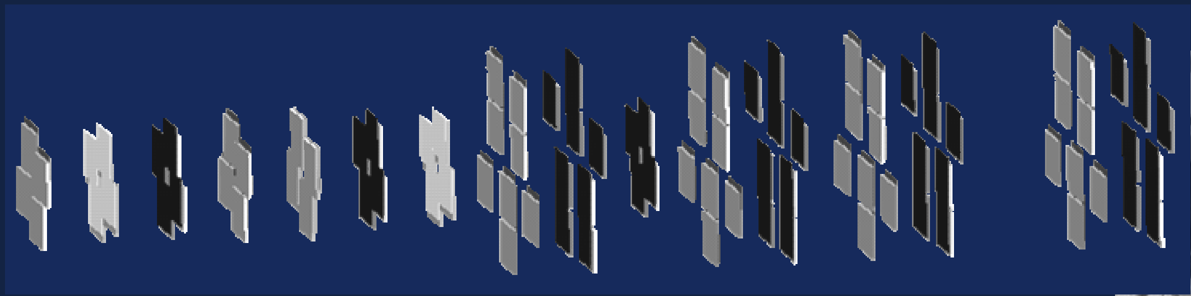
Zero Degree Calorimeter: forward energy → centrality (Cherenkov quartz)



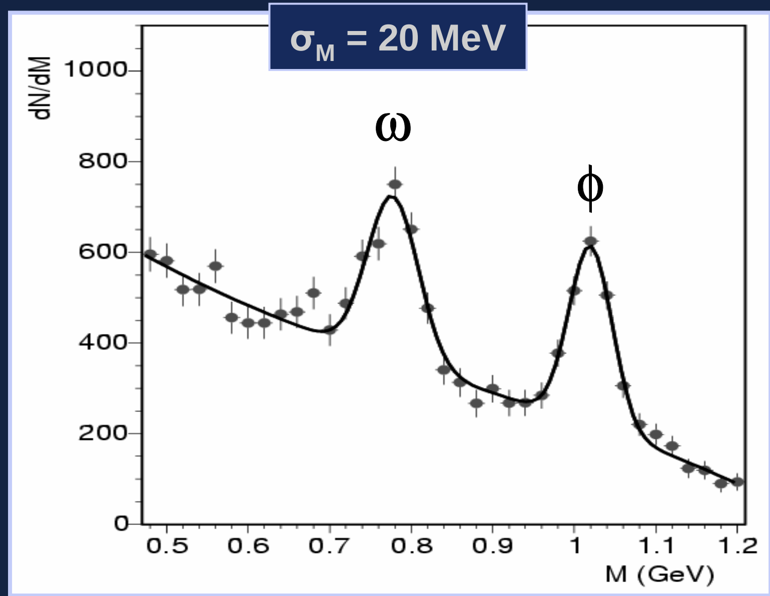
new readout

- NA50 – transputers, VME FEP, VAX/VMS
- NA60 – PCI-FLIC card, PC/Linux

Pixel Telescope

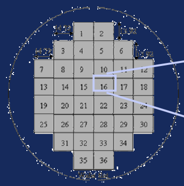


- 11 tracking planes (~3% X_0 per plane)
  - 8 small 4-chip + 8 big 8-chip planes
  - 96 assemblies, 786432 channels
- ALICE1LHCB pixel chip (8192 pixels, 10 MHz)
  - 256x32 matrix, 50x425 μm^2 pixel, 12.8 × 13.6 mm^2 active area, 750 μm thick
  - radiation tolerant up to ~20 Mrad
  - local threshold, 4-event buffer
- mass resolution: from ~75 → ~20 MeV in ω/φ region
- position resolution ~20 μm in transverse plane at the target

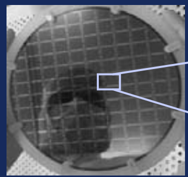


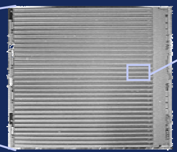
Pixel Telescope – production

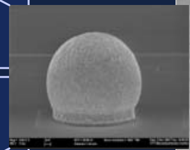
Si
sensor

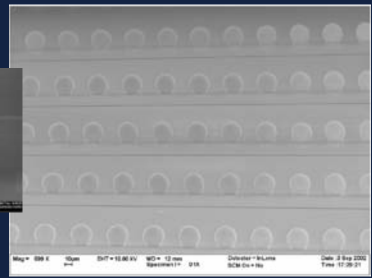


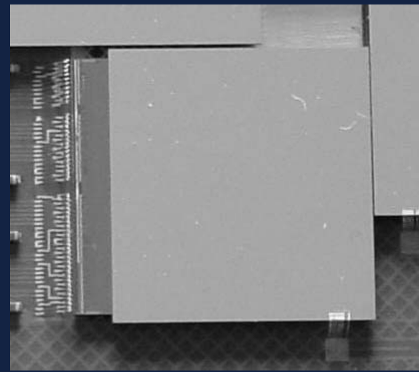
pixel
chip









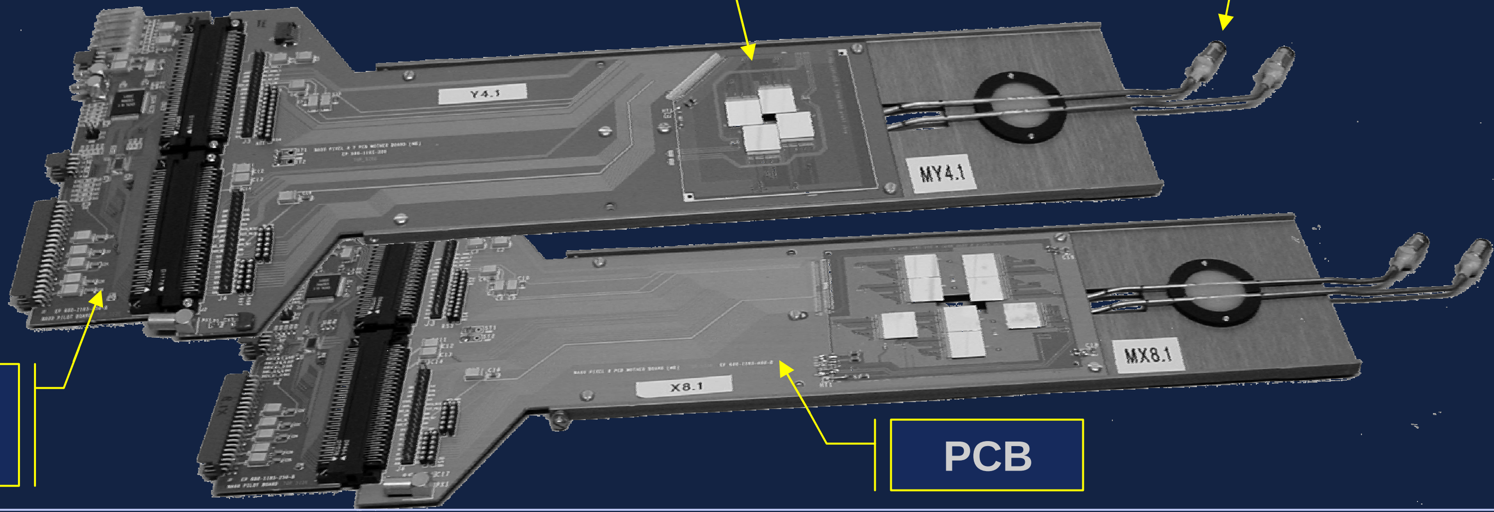


wafer **one chip** **bump-bonding** **one assebmly**

fully assembled
module

hybrid with assemblies

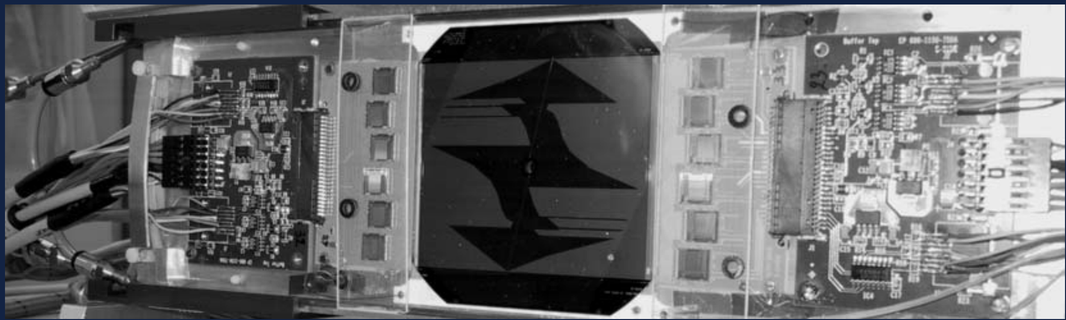
cooling



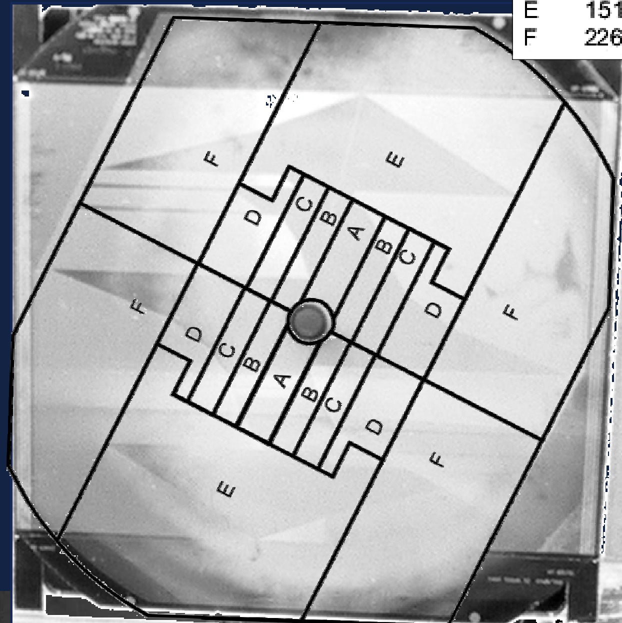
readout electronics

PCB

Silicon microstrip telescope



	Pitch(μm)
A	80.00
B	60.00
C	80.00
D	134.91
E	151.06
F	226.96



8 double planes of 300 μm silicon sensors

- double-metal, DC coupled, Al/p+/n/n+/Al
- 90 mm diameter, beam hole
- 1536 strips, variable pitch/size geometry
- **~ 0.3% X_0** per plane, **occupancy < 3%**

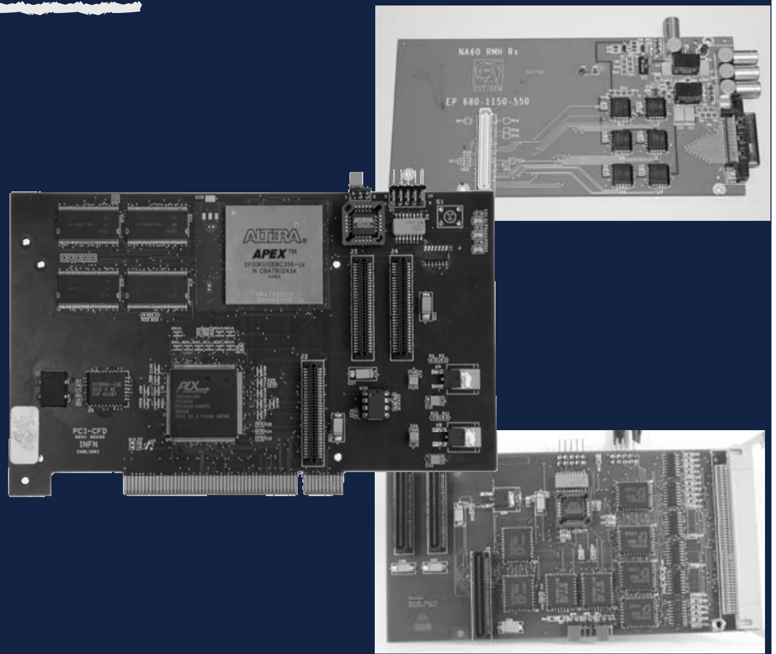
ATLAS SCTA read-out chips

- **40 MHz** operation
- **analog** sampling

Readout, DAQ, Controls

PCI readout (crate=PC) for all detectors

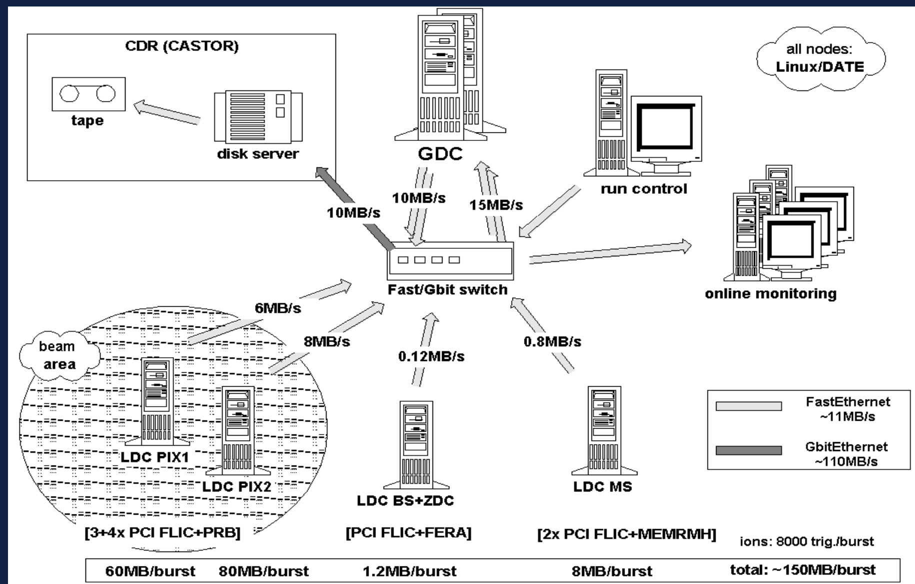
PCI-CFD readout board
- 40 MHz Altera FPGA, 64 MB SDRAM
- spill buffering, ~30 MB/s through PCI
- detector-specific mezzanines - PRB (Pixels), RMH (Muon Spectro), FERA (Beam Tracker, ZDC)



SSPCI readout board for Strips
- synchronous, SLINK mezzanine

DAQ – PC/Linux, spill buffering
- based on DATE framework of ALICE

Controls – PVSS, LabVIEW, OPC
Wago PLC, CAEN power supplies

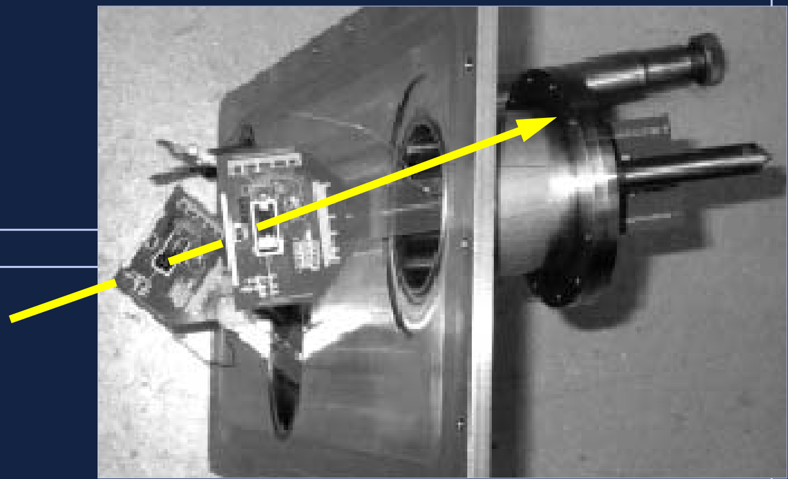


Beam Tracker

requirements

- determine the position of the incoming particle in the beam ($\sigma \approx 20$ μm)
- beam pileup reduction

- ultra radiation hard
  - $\approx 10^{11}$ ions/day, $\approx 10^{12}$ protons/day $\Rightarrow$ dose $\approx$Grad/day (area ≈ 1 mm^2)
  - should survive couple of weeks $\Rightarrow$ tens of Grad of dose
- fast readout
  - up to 10^7 ions/s or 10^8 protons/s
  - sampling O(1) ns



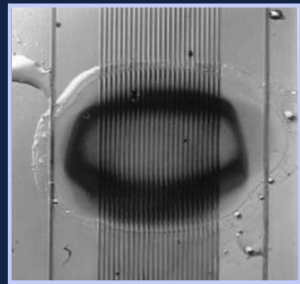
solution

- silicon strip sensor
- two tracking stations of two (x, y) sensors
- cryogenic operation as a radiation hardening technique
  - “Lazarus effect”

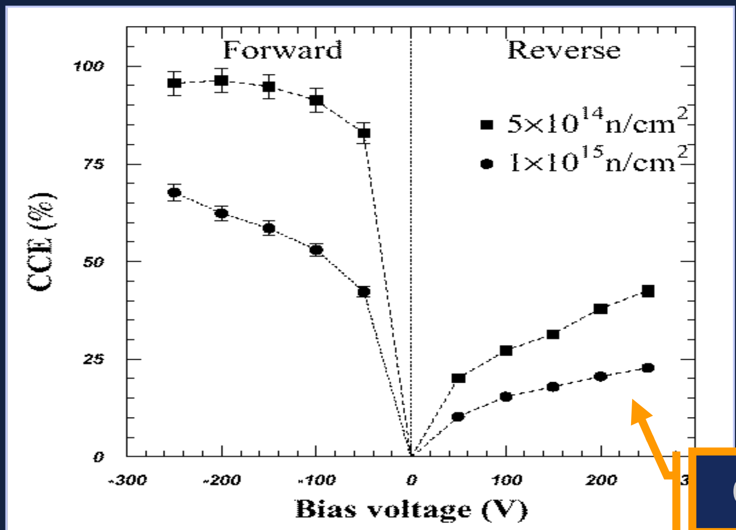
Lazarus effect

- discovered in 1998, studied by RD39
- first prototype in 1999 – common RD39/NA60 project

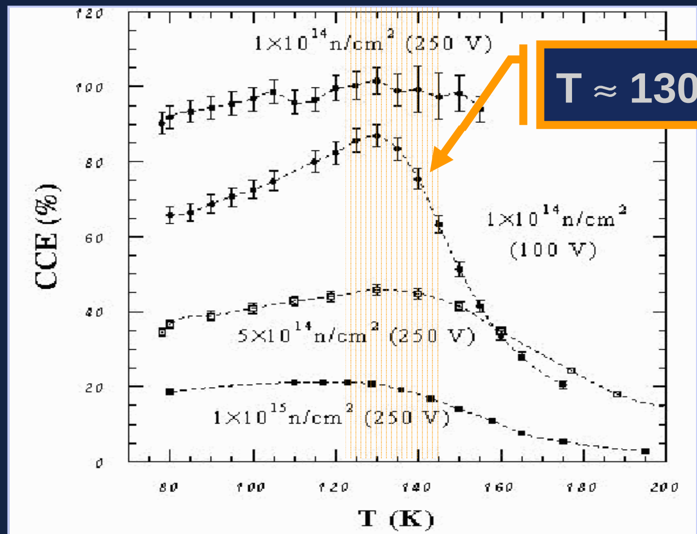
- **cryogenic operation - CCE regeneration of irradiated silicon detectors**
  - radiation damage ⇒ traps ⇒ partial depletion, signal distortion
  - low temperature ⇒ traps “frozen” (electrically inactive)
    - de-trapping time ~exp(-1/kT) (~ minutes)
  - very low leakage current, fast signals
  - trap-filling – particles, forward bias, light



- tests up to ≈10^{15} neutrons(1MeV)/cm^2
- optimal temperature ≈130K



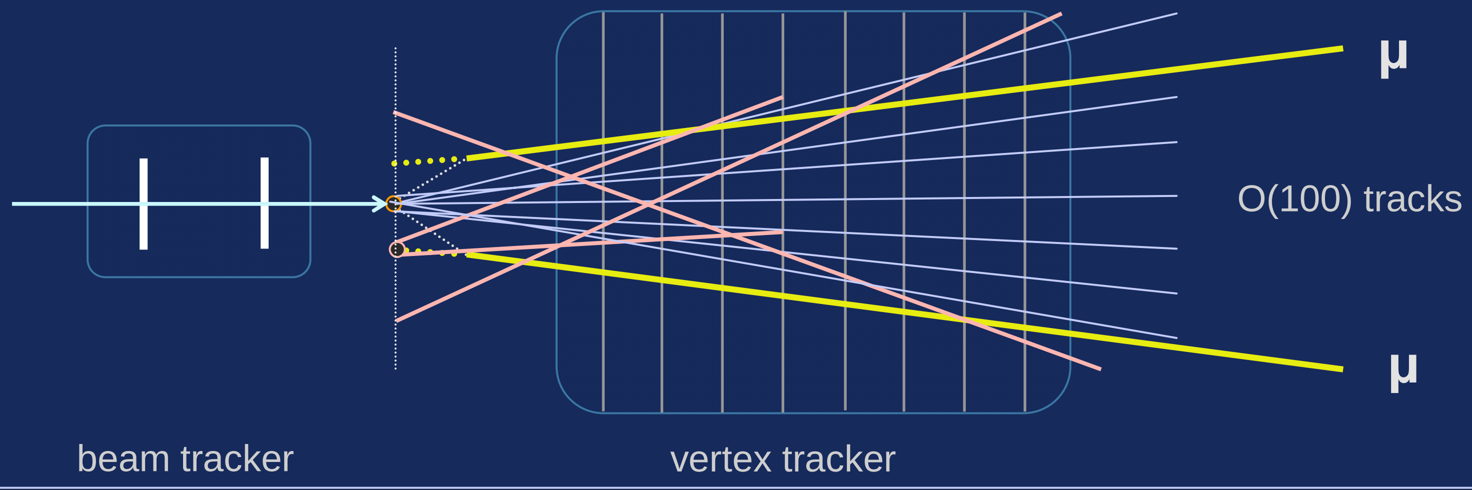
CCE > 20%



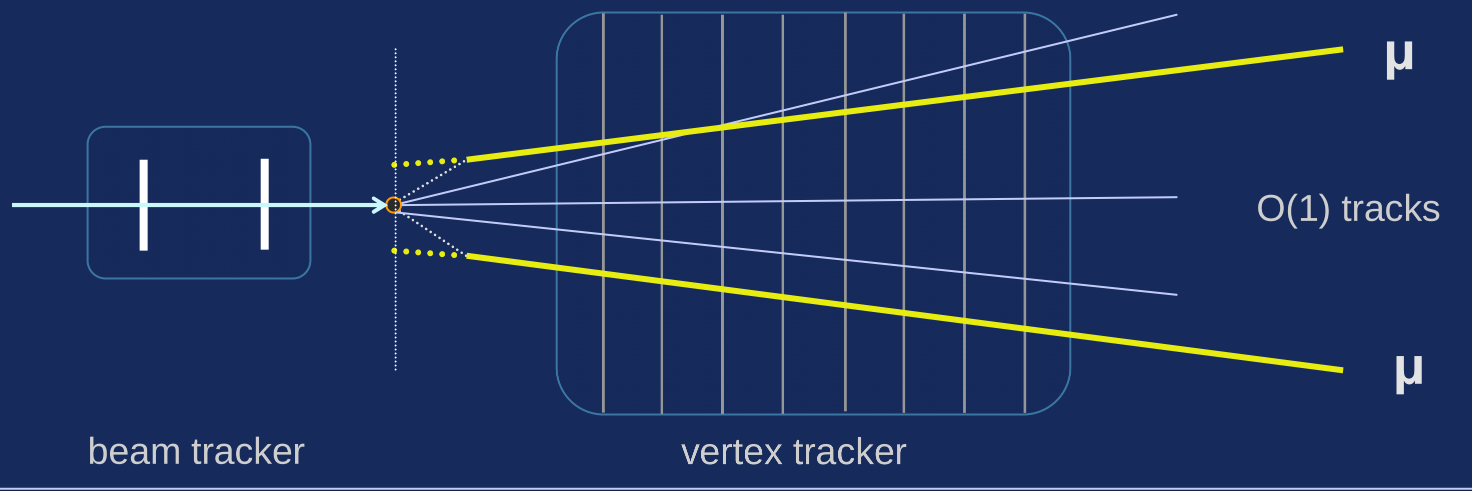
T ≈ 130K

Beam Tracker – vertexing

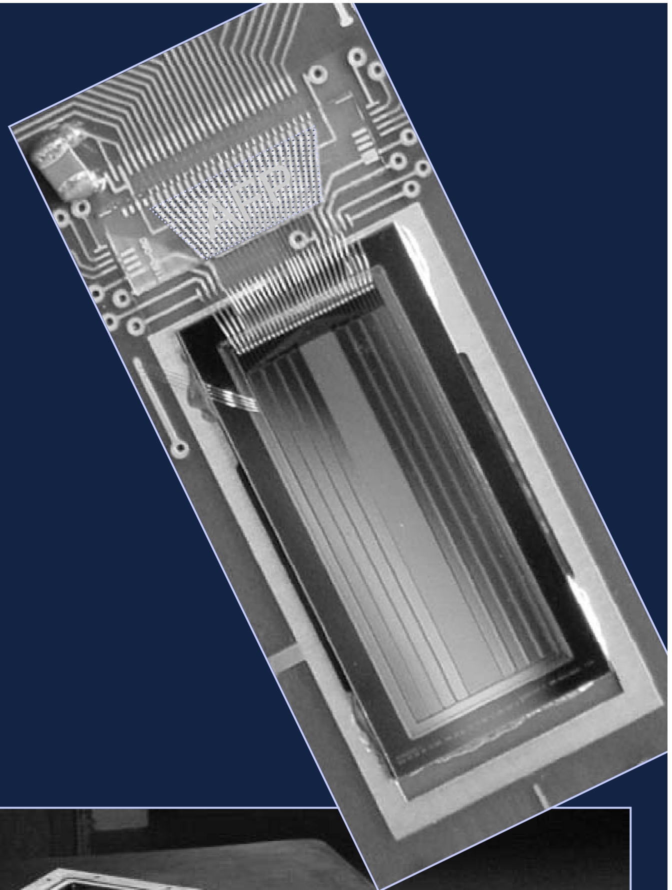
ion collisions – constraint for the tracking



proton collisions – improve position resolution



Beam Tracker



sensor

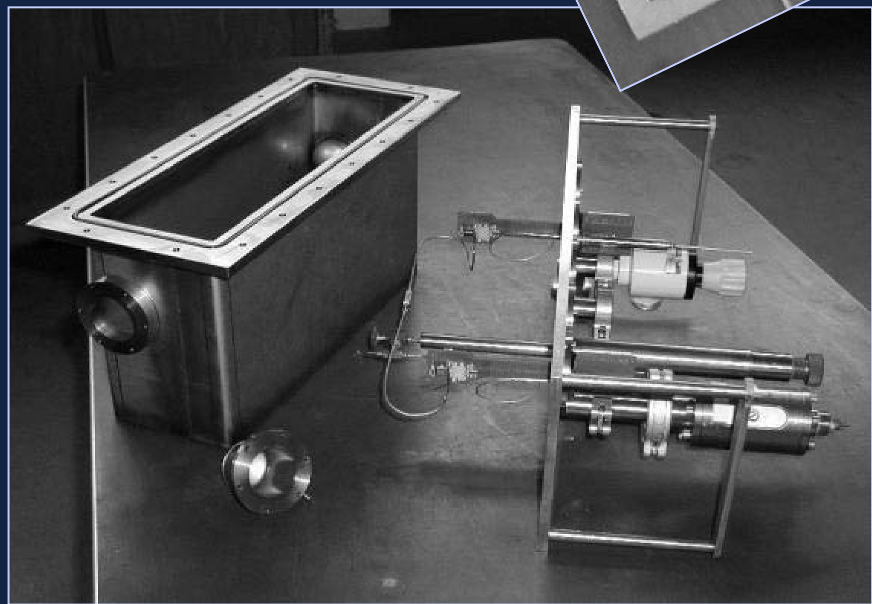
- single-sided silicon strip detector
- n-substrate, p+ strips (Al/p+/n/n+/Al), DC coupling
- 400 µm thickness, active area of 1.2 mm wide
- 24 tracking strips of 50 µm pitch
- 4+4 wide strips of 50 µm pitch for beam steering
- backplane can be used in trigger, excellent timing

PCB

- multilayer, special thermal design
- AFP “proton” chip or pitch adapter

vaccuum cryostat

- stainless steel with beam windows
- LN2 open-cycle

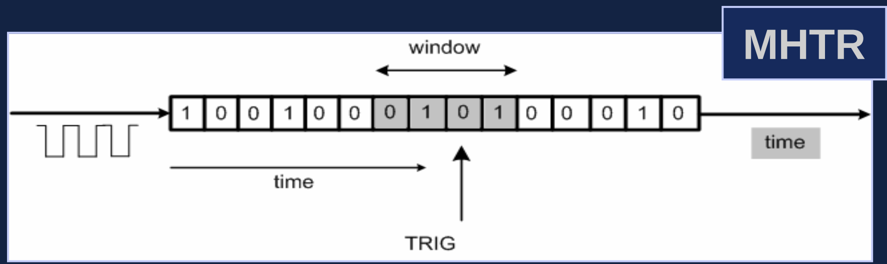


Beam Tracker - readout

- **fast low-noise preamplifiers**
  - risetime 1.7 ns, gain up to 200; total noise 25 µVolts rms

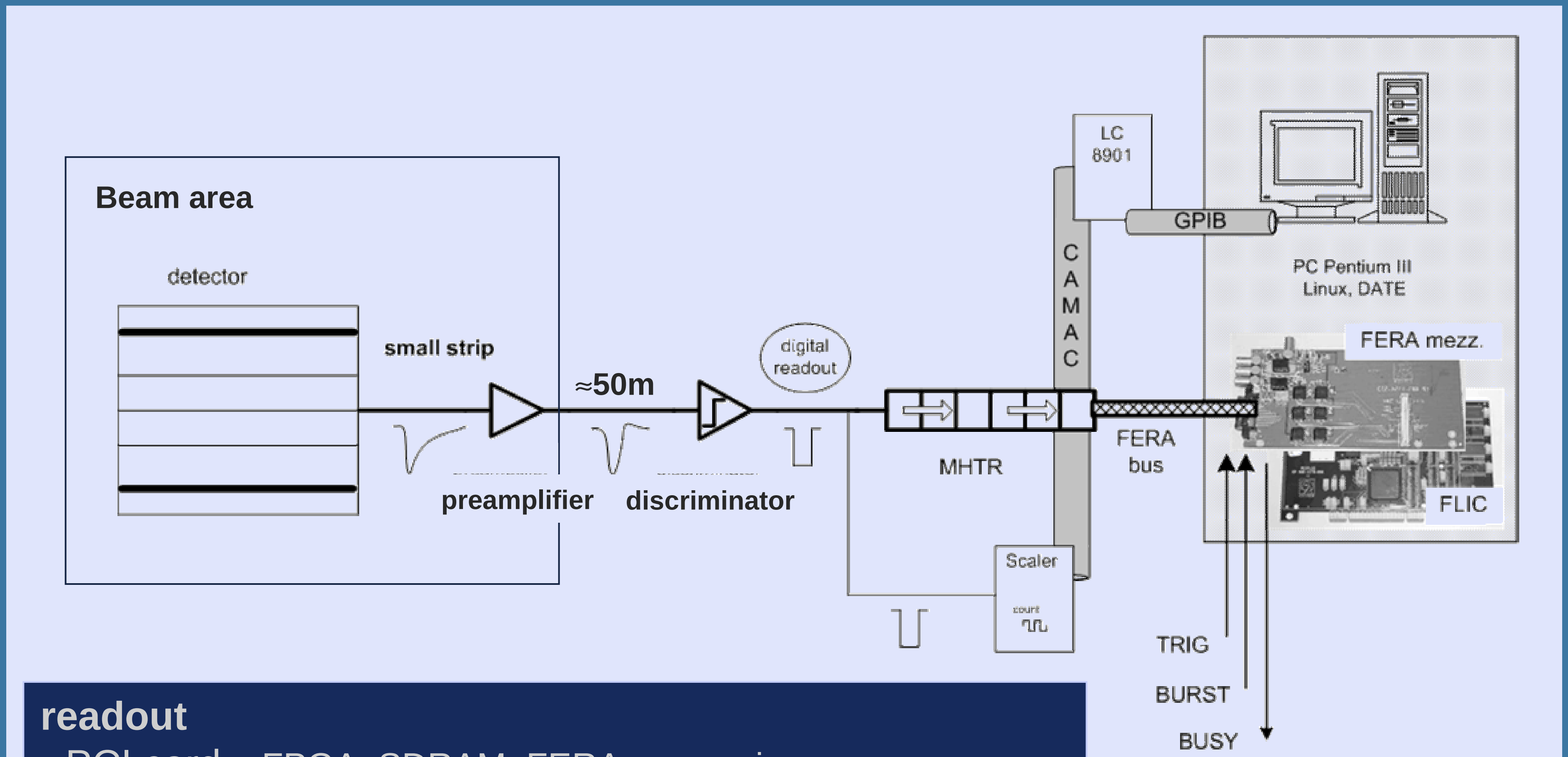
- **AFP "proton" chip**
  - Active Feedback Preamplifier (uses feedback transistor)
  - 32 channels, 0.25 µm CMOS

- **discriminators**
  - 8 channels, CAMAC, combined with scalers, ECL port for MHTR
  - programmable threshold, mask



- **MHTR recorders**
  - **M**ulti **H**it **T**ime **R**ecorder, 1.7 ns step
  - ALTERA MAX7000, 600 MS/s (4x interleaved)
  - ALTERA FLEX10k EPLD, 2 kbit buffer per channel (past 3.4 µs)
  - programmable window around the trigger, encoded hit time
  - 8 channels, CAMAC, FERA

Beam Tracker – readout

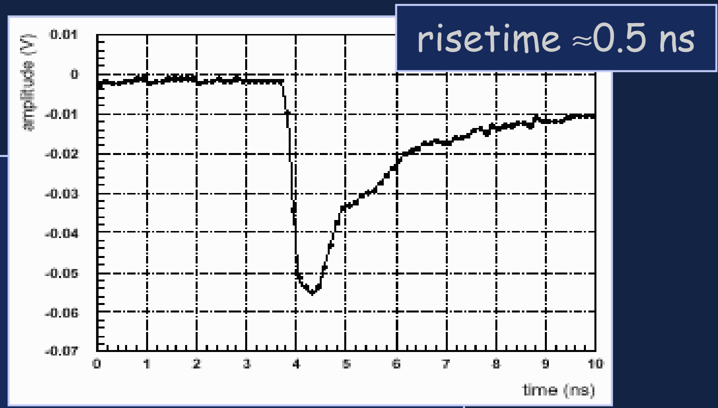


readout

- PCI card – FPGA, SDRAM, FERA mezzanine
  - PCI-FLIC (CERN-EP/ED) – development
    - ORCA FPGA, 32 MB
  - PCI-CFD (Cagliari, NA60 standard) – since 2003
    - ALTERA FPGA, 64 MB

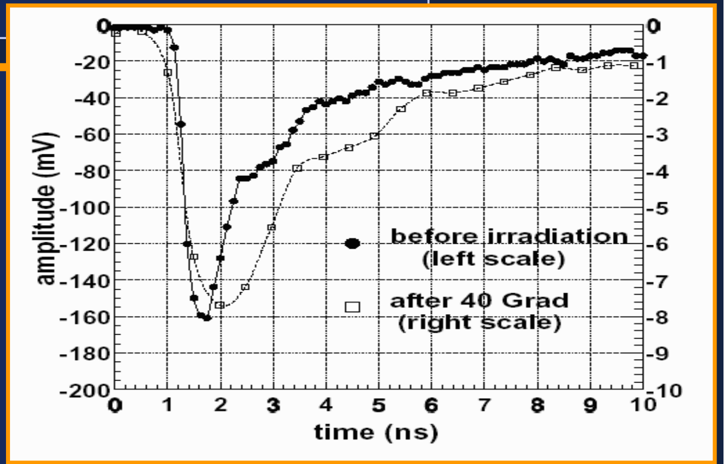
Beam Tracker tests

1999 – feasibility test in heavy ions
- 3 days in 40 GeV/A Pb, SPS
- ≈6x10^{12} ions/cm^2 accumulated (≈1 Grad)
- fully functional prototype (preamp's, MHTRs)
- fast pulses, beam profile → beam steering



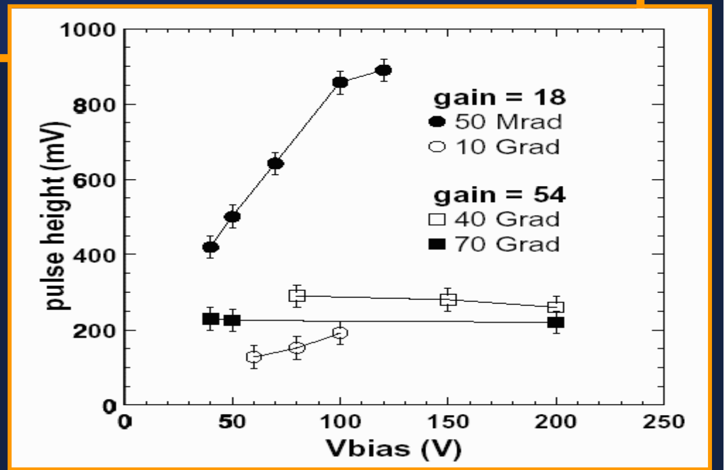
2000 – long-term irradiation test

- 42 days in 158 GeV Pb, SPS
- ≈**5x10^{14} ions/cm^2** accumulated (≈90±40 Grad)
- substantial degradation observed
- tuning: 3x gain, max. bias voltage
  ⇒ operational till the end



2001 – feasibility proton test

- 1 week, 400 GeV protons, SPS
- very small dose ≈4x10^{14} protons /cm^2 (≈10 Mrad)
- AFP "proton" chip
- suitable for NA60

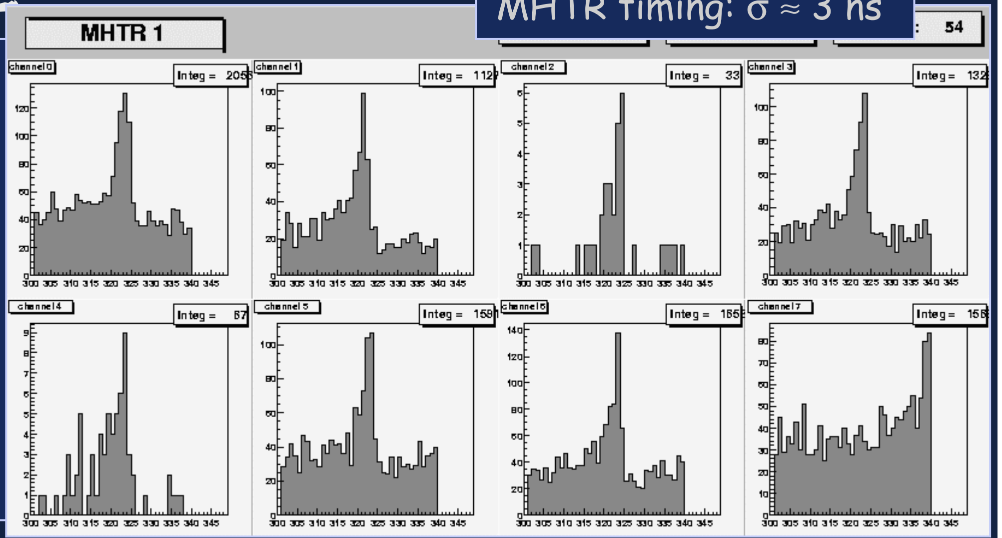


Beam Tracker runs

2002 – proton run

- 22 days, 400 GeV protons, SPS
- up to ~2x10^8 p/burst
- fluence ≈4x10^{15} p/cm^2 (≈0.1 Grad)

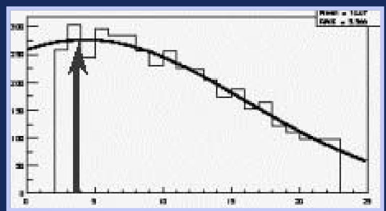
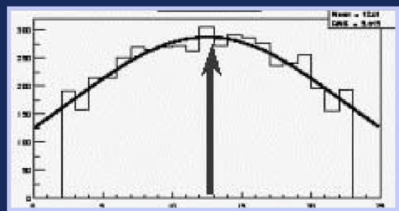
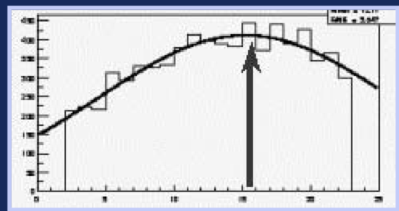
MHTR timing: $\sigma \approx 3$ ns



2002 – low-intensity heavy ion run

- 10 days, 20/30 GeV Pb, SPS, ~10^6 i/burst
- fluence ≈2x10^{11} ions/cm^2 (≈30 Mrad)
  - efficiency: ≈96% → ≈86% at 300K, 99.6% in cold (130K)

- in-burst beam swing observed (~500 μm)

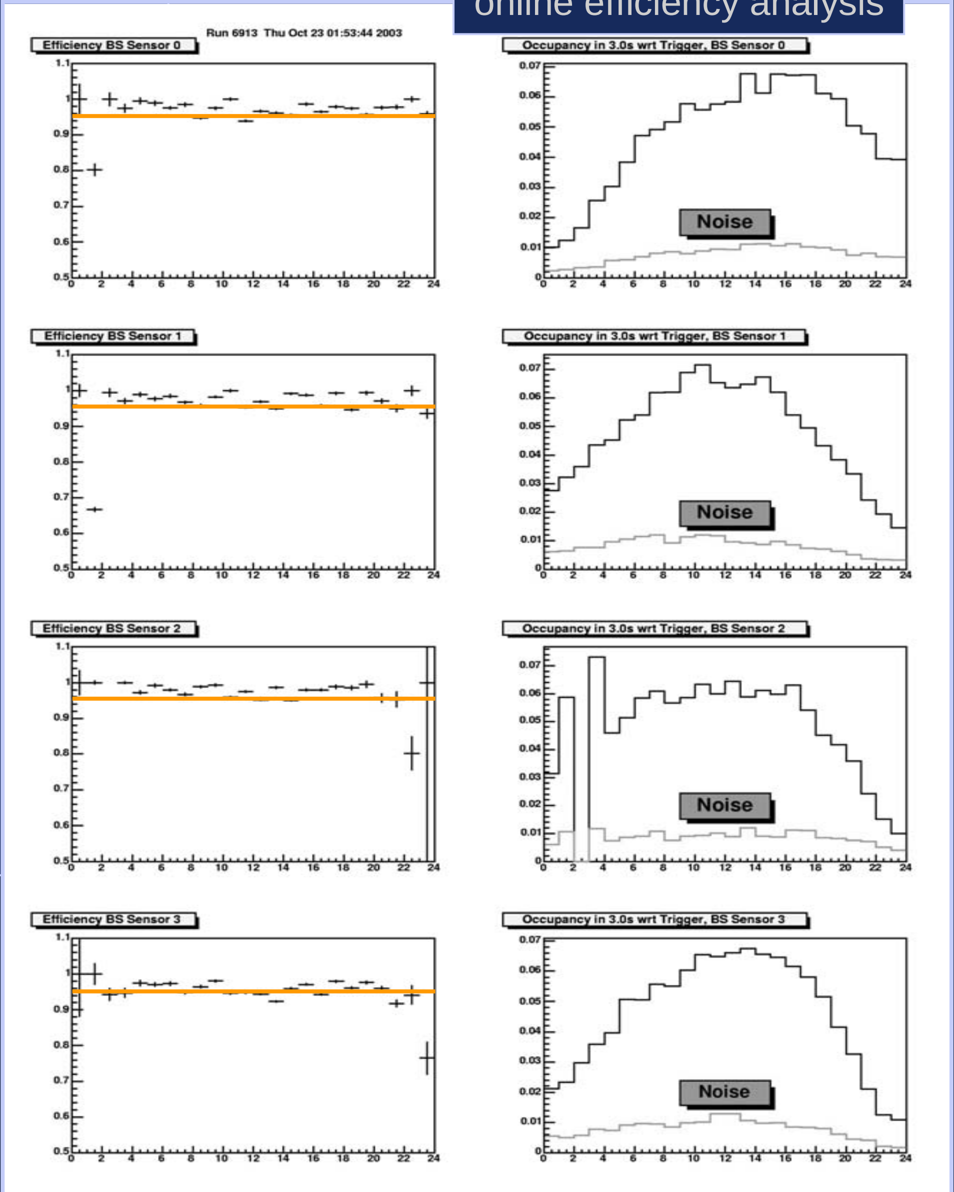
Beam Tracker – latest run

2003 – indium run

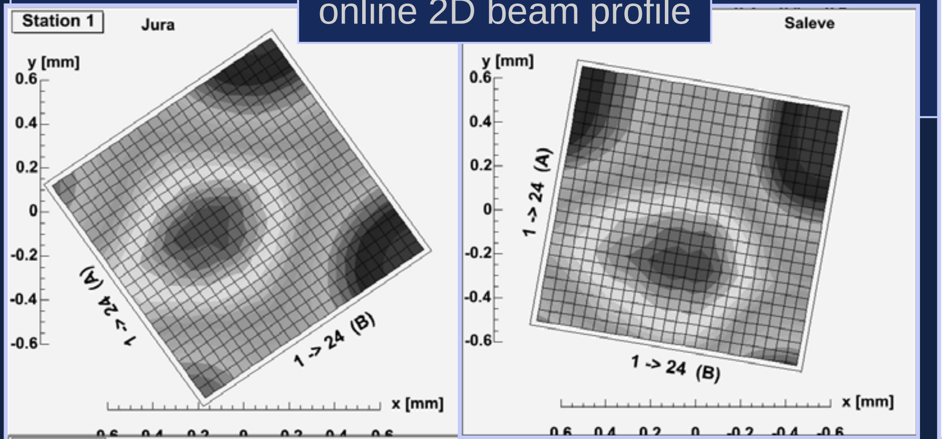
- 5 weeks, 158 GeV indium, SPS
- two sets used (change after 3 weeks)
- 1st set: ≈9×10^{13} ions/cm^2 (≈5.5 Grad)
- 2nd set: ≈6×10^{13} ions/cm^2 (≈3.7 Grad)

- tuning during the run
  - bias voltage 40V → 250V
  - monitoring the noise
  - efficiency usually >95%

online efficiency analysis



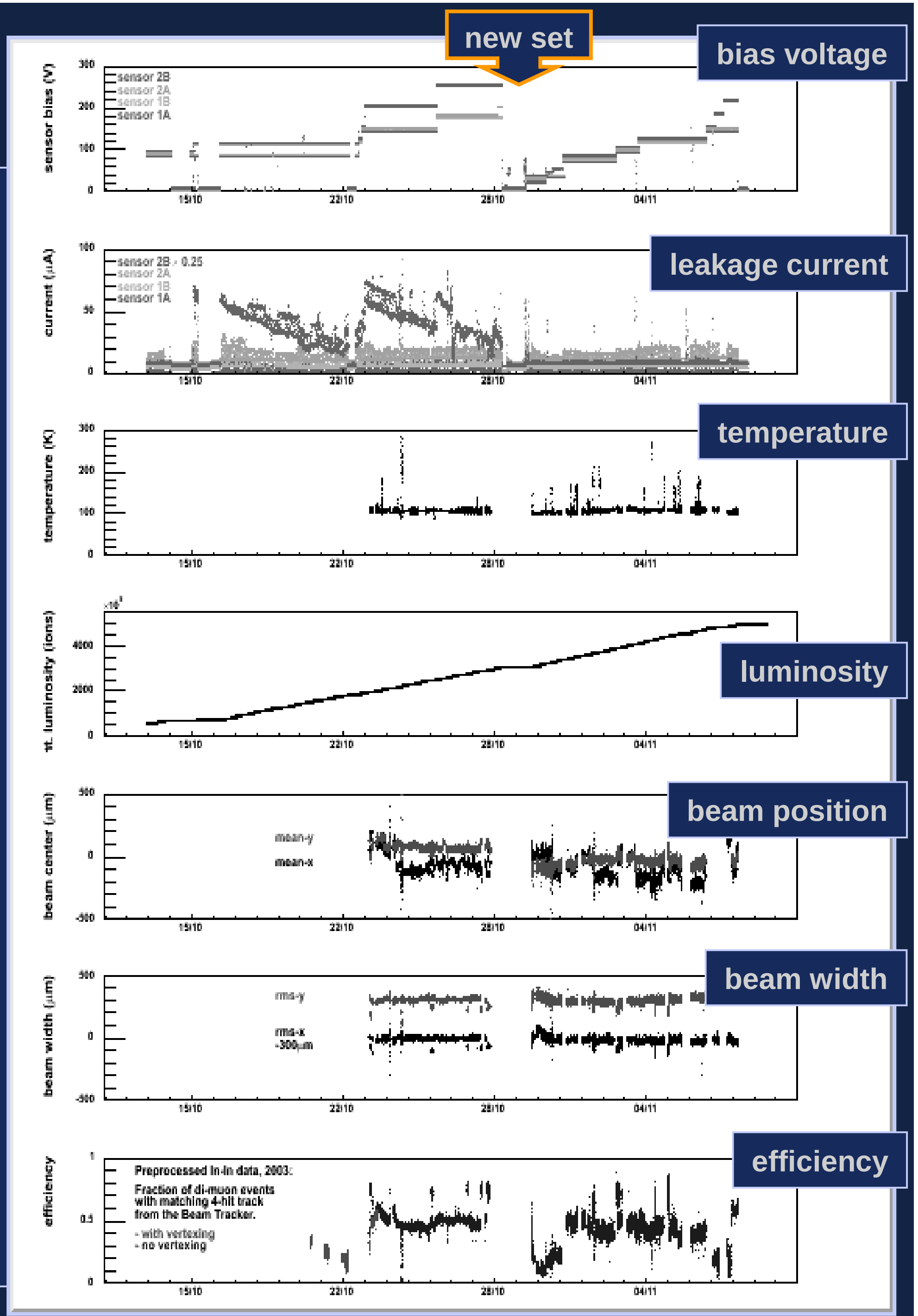
online 2D beam profile



Beam Tracker

indium run overview

- bias voltage
  - up to 250 V
- leakage current
  - ≈microamps (2B: tens of μA)
- temperature
  - stable around ~130 K
- luminosity on the backplane
  - $\approx 3 \times 10^{12}$ (1st set), $\approx 2 \times 10^{12}$ (2nd set)
- beam position
  - variations O(100 μm)
- beam width
  - normal: RMS ≈300 μm
  - narrow periods: ≈230 μm
- combined 4-sensor efficiency
  - not corrected for the acceptance
  - ~50% (~75% narrow beam)
  - ⇒ single effi: ~85% (~93%)



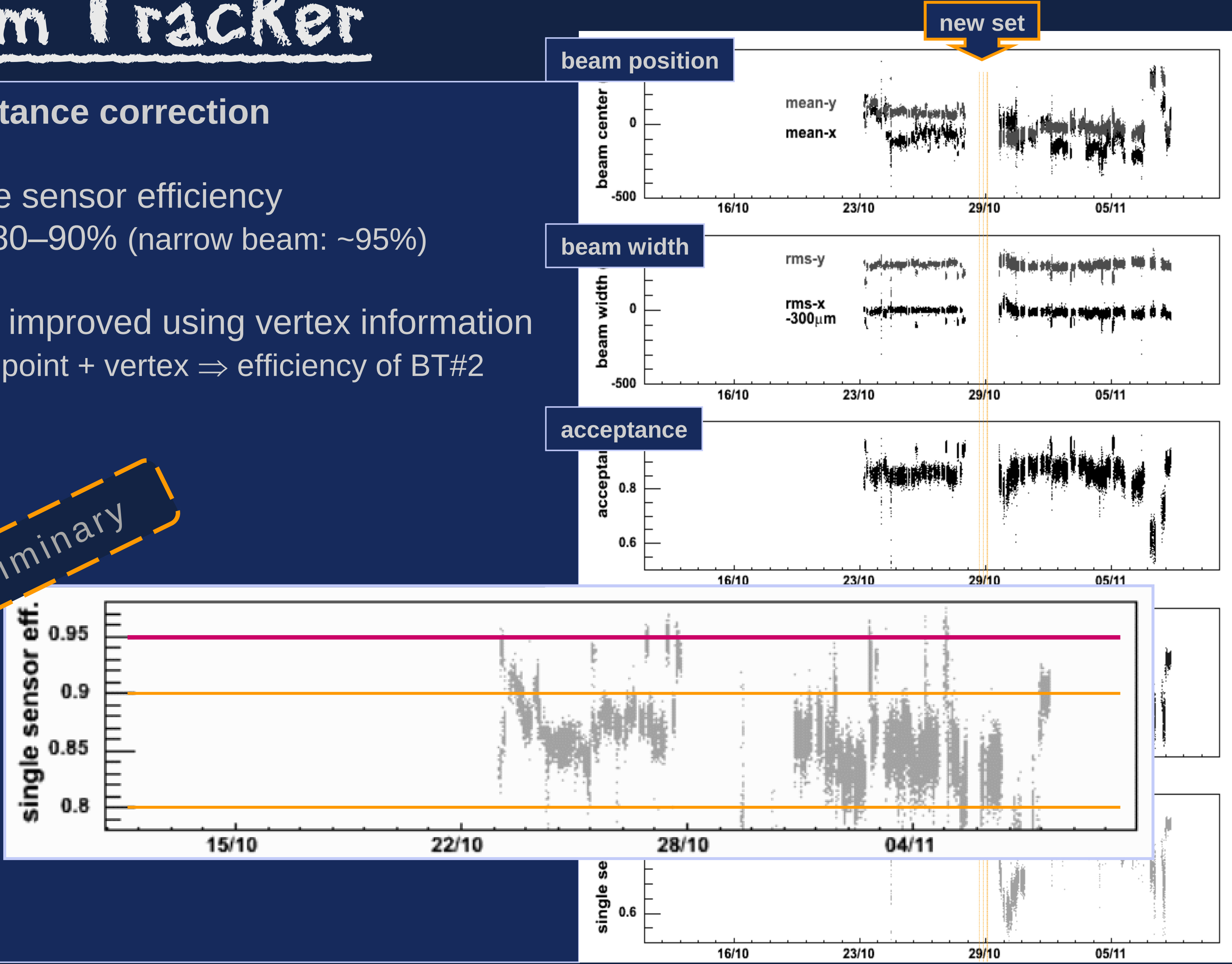
Beam Tracker

acceptance correction

- single sensor efficiency
  ~80–90% (narrow beam: ~95%)

- to be improved using vertex information
  BT#1 point + vertex ⇒ efficiency of BT#2

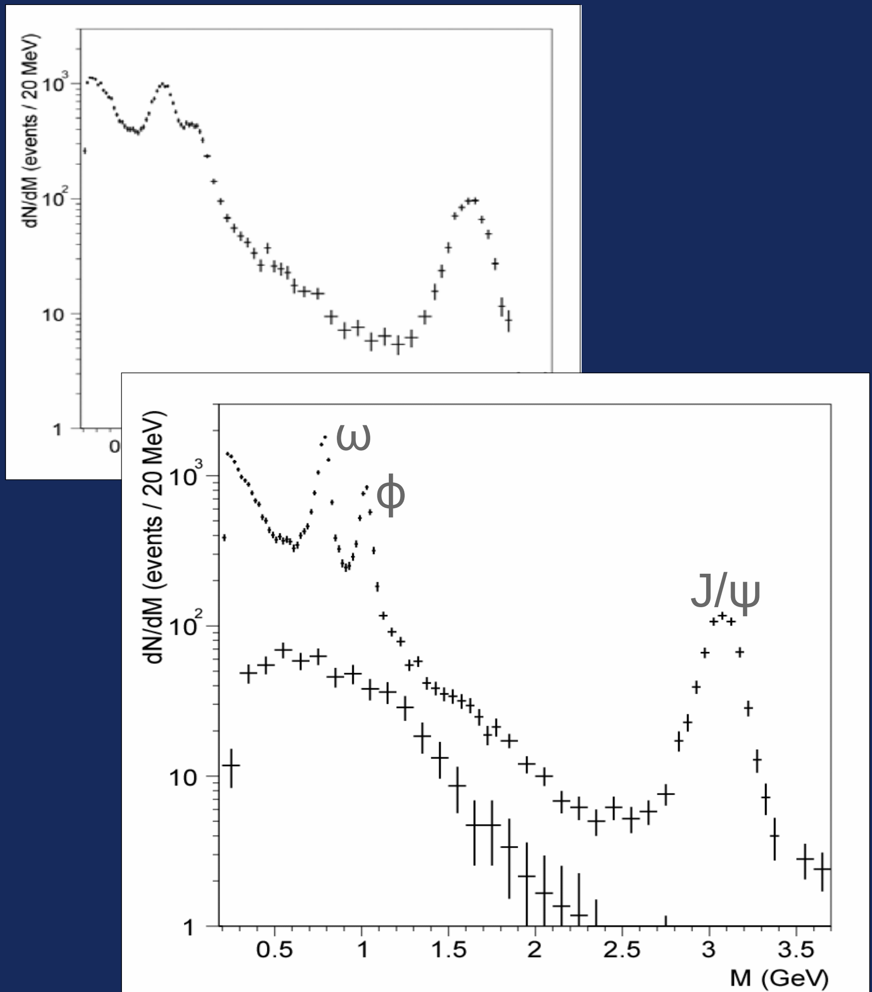
preliminary



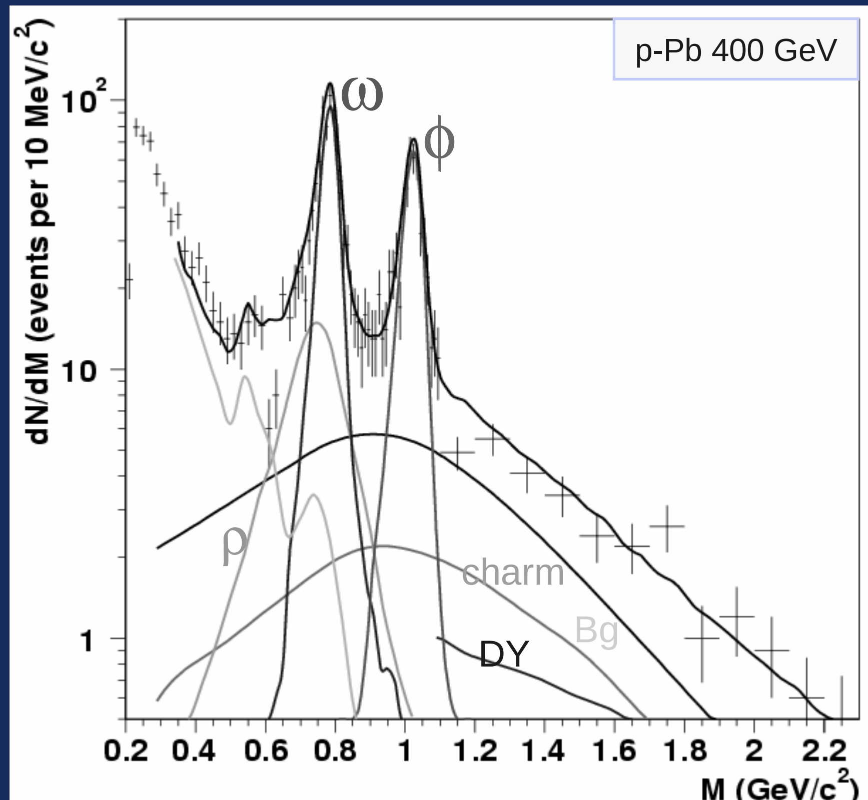
Proton run in 2002

- 400 GeV protons, low intensity, Microstrip Telescope

muon track matching ⇒ σ_{ω} = 25 MeV



low mass spectrum with ~ 1% of the estimated 2004 statistics

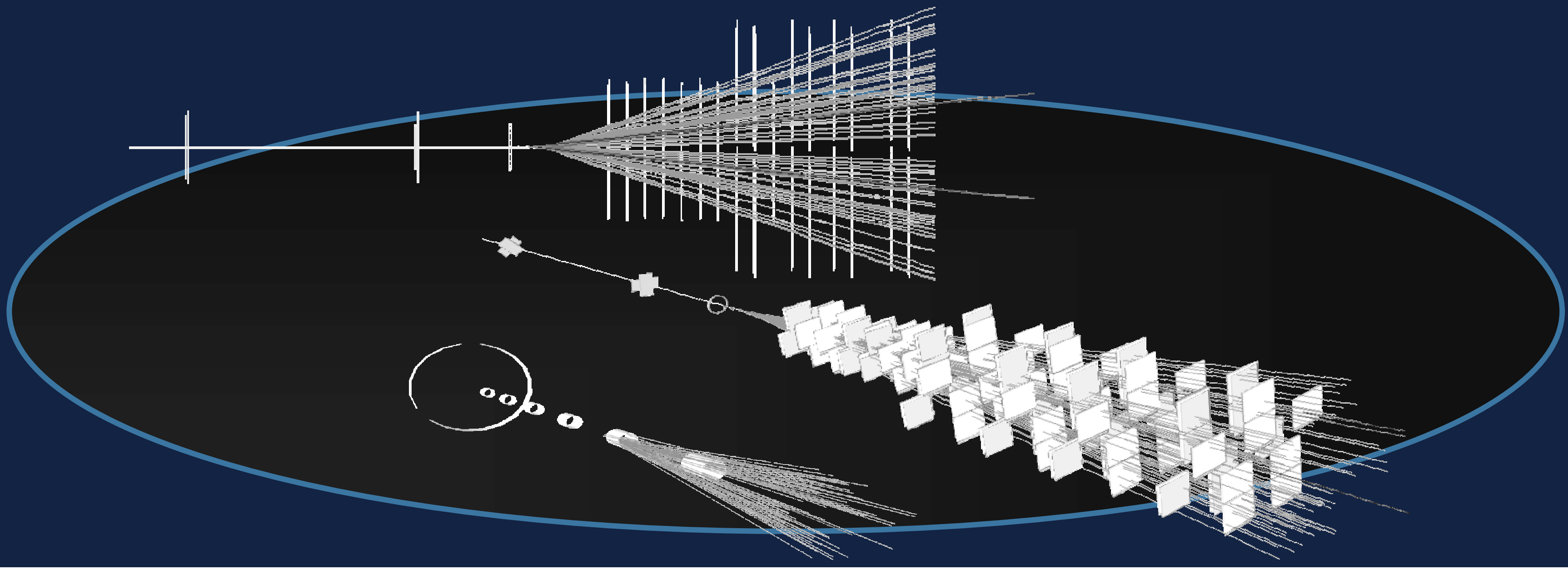


Indium run '2003

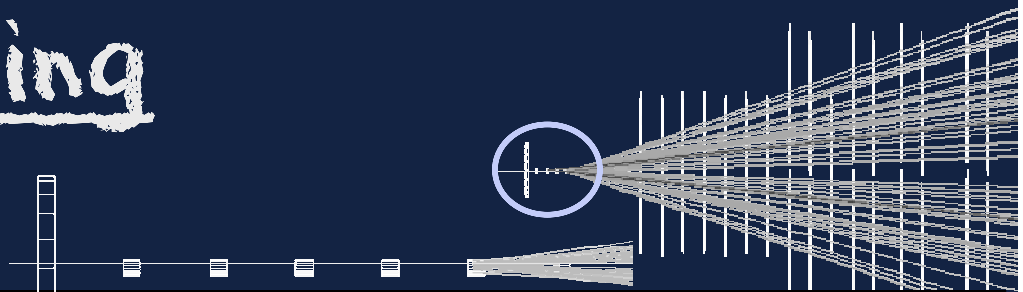
- 158 GeV Indium beam on 7 Indium targets

- 5-weeks (Oct-Nov 2003)
- ≈4x10^{12} ions delivered
- 230 million dimuon triggers acquired
- ≈3 TB of data on tapes

- more than 100 000 J/ψ events (before track matching)
- around 1 million low mass dimuons (after track matching)

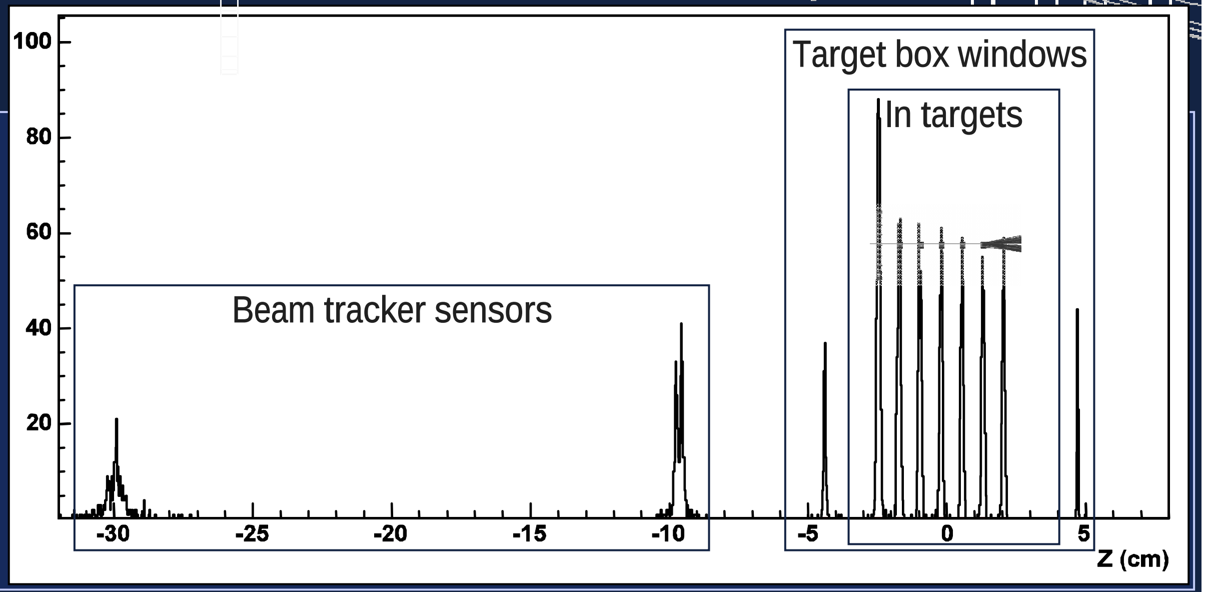


In '2003 – vertexing



Z-vertex
determination
from pixel telescope

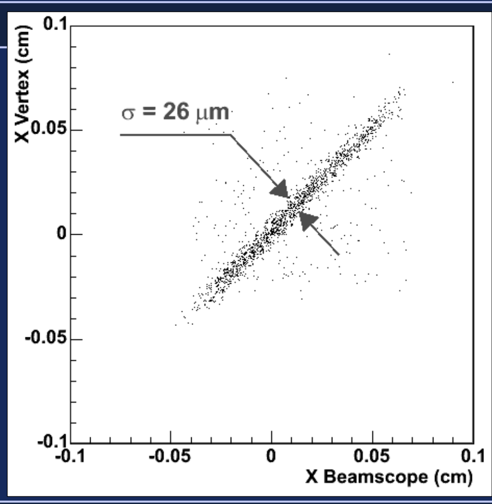
σ_z = 300 μm

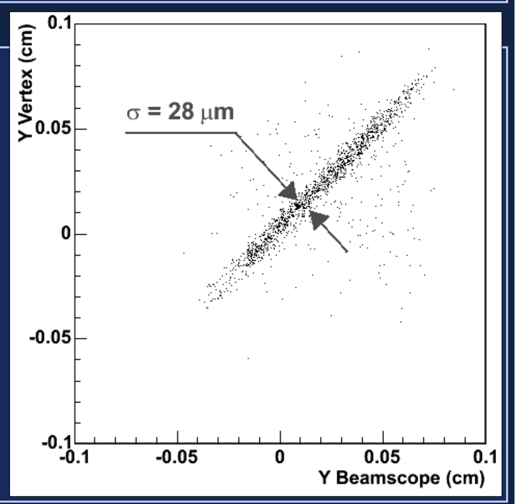


Transverse coordinates
measured
by the pixel telescope
and the beam tracker

- $\sigma_x \approx 26$ μm, $\sigma_y \approx 28$ μm

  ⇒ both better than ≈20 μm

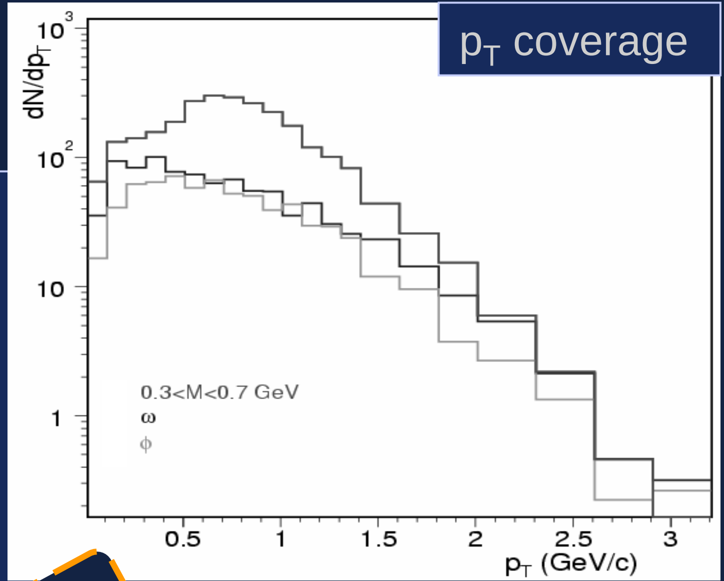




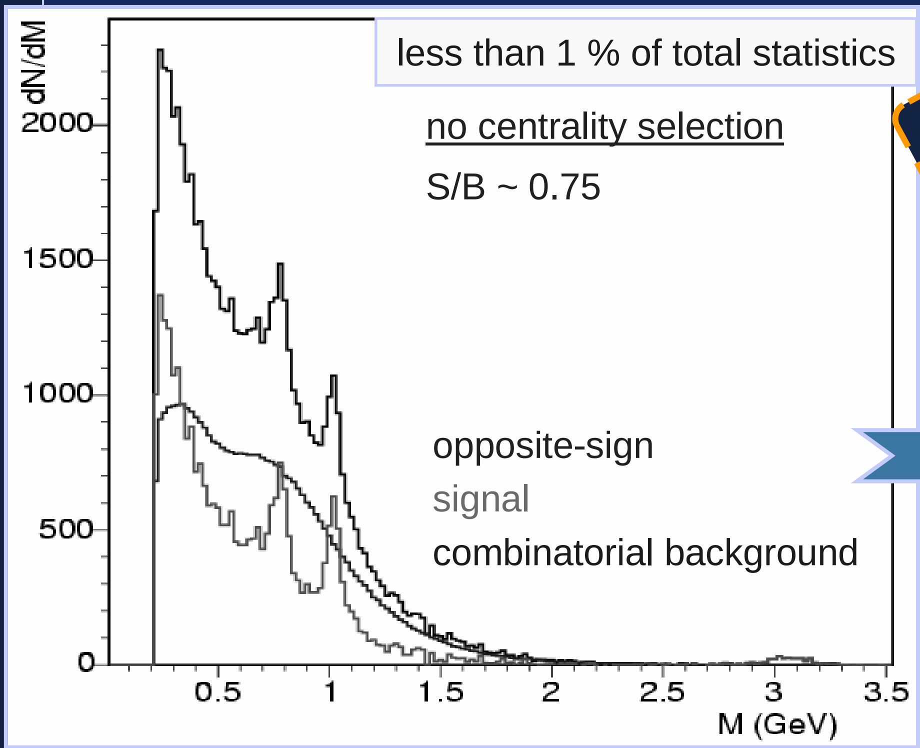
In '2003 – low mass

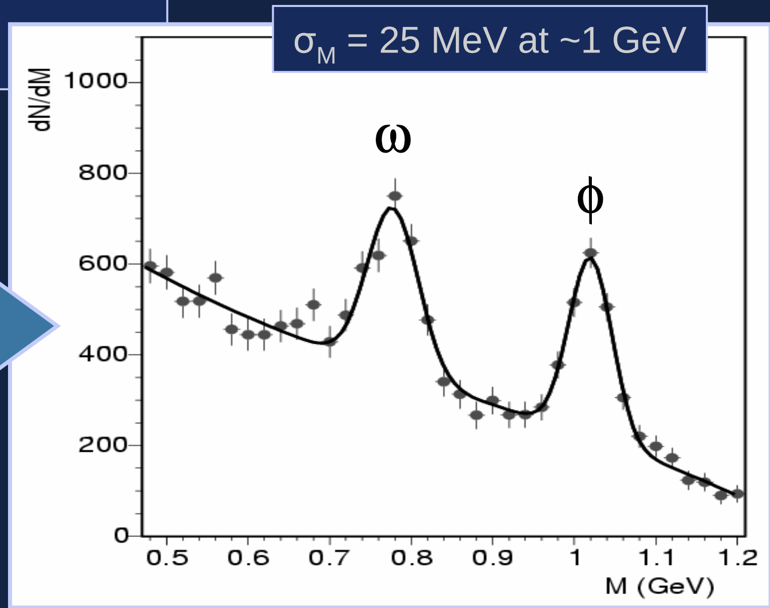
low mass region

- improved mass resolution after track matching
- from 75 MeV to 25 MeV at ~1 GeV
- good p_T coverage in the low mass region
  - down to zero p_T (no centrality selection)



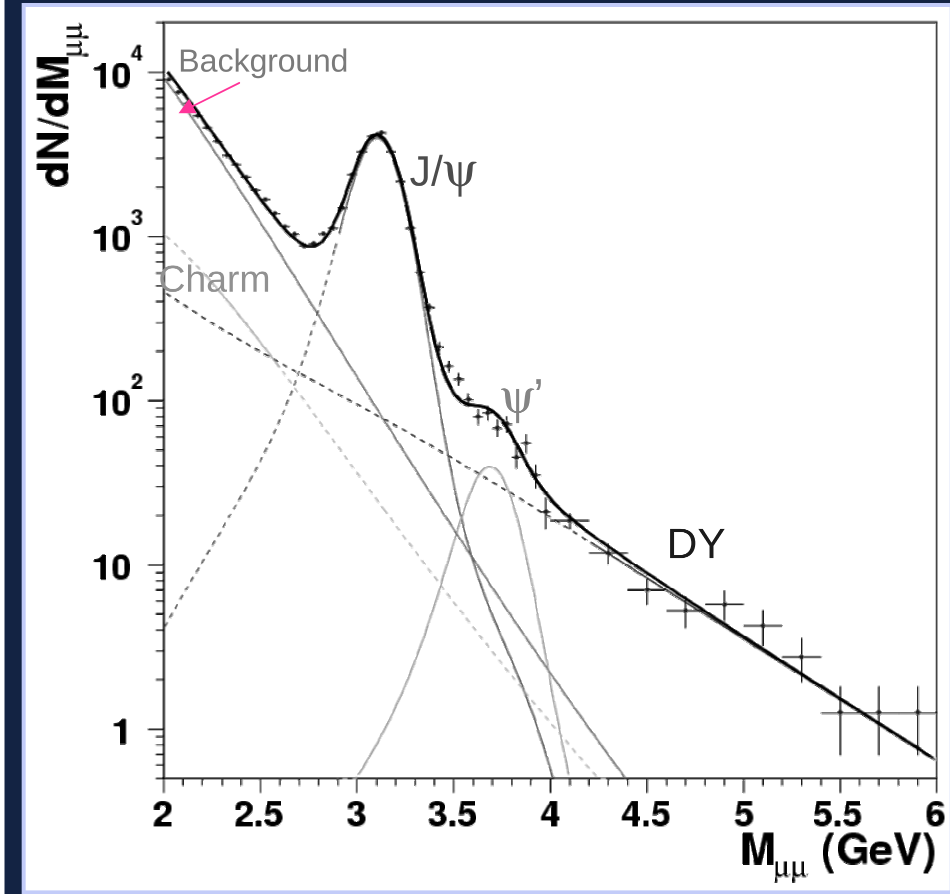
preliminary





In '2003 – first results

preliminary



Dimuon data from the 6500 A event sample
No muon track matching used in this analysis
Mass resolution at the J/ψ : ~107 MeV

Combinatorial background from π and K decays estimated from the measured like-sign pairs

Signal mass shapes from Monte Carlo:
- ✓ PYTHIA and MRS A (Low Q^2) parton densities
- ✓ GEANT 3.21 for detector simulation
- ✓ reconstructed as the measured data

Acceptances from Monte Carlo simulation:
- ✓ for J/ψ : 12.4 %
- ✓ for DY : 13.4 % (in mass window 2.9–4.5 GeV)

A multi-step fit (max likelihood) is performed:

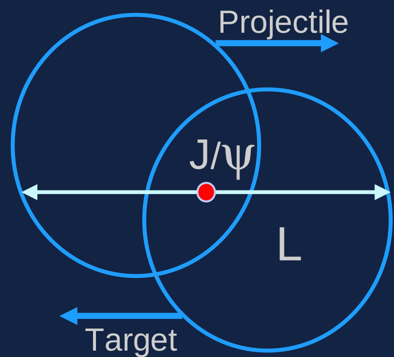
a) M > 4.2 GeV : normalise the DY → DY yield = 1302 ± 104 in mass window 2.9–4.5 GeV

b) 2.2<M<2.5 GeV: normalise the charm (with DY fixed)

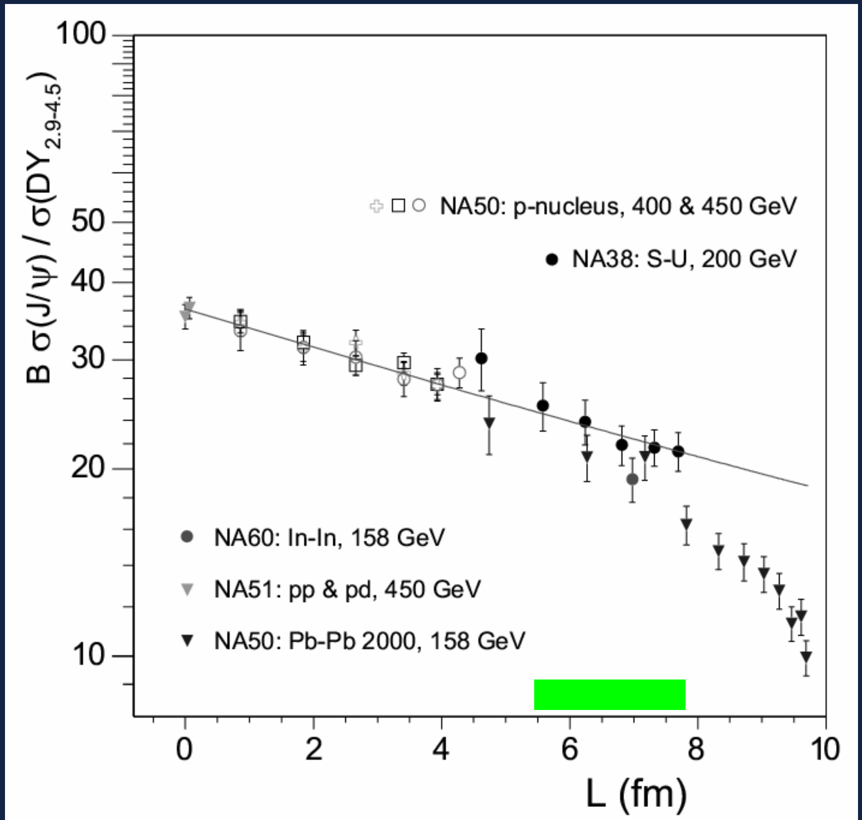
c) 2.9<M<4.2 GeV: get the J/ψ yield (with DY & charm fixed) → J/ψ yield = 23532 ± 298

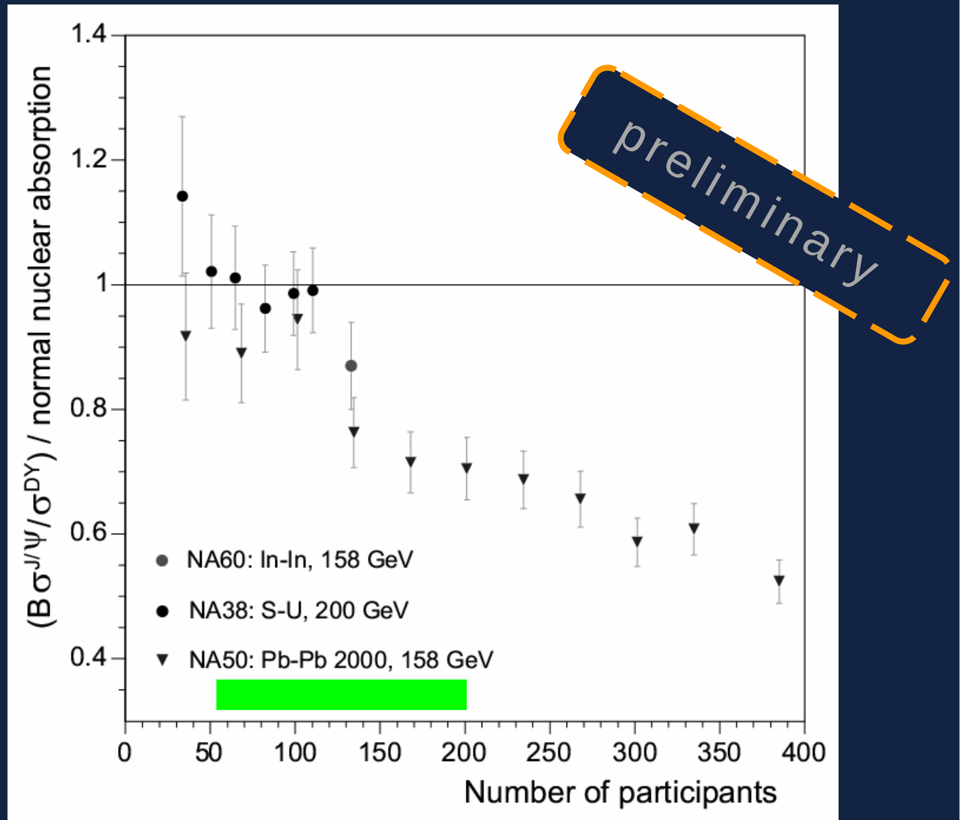
In '2003 – first results

B σ(J/ψ) / σ(DY) = 19.5 ± 1.6 ⇒ 0.87 ± 0.07 w.r.t. the absorption curve



In-In collisions of E_{ZDC} < 15 TeV ⇒ L = 7.0 fm and N_{part} = 133
(from Glauber fit to the minimum bias E_{ZDC} distribution)





Stability checks: Background increase by 10% : less than 3% change
Different event selection : less than 8% change
Using GRV parton densities instead of MRS : 0.87 ± 0.07 → 0.93 ± 0.08

Summary and outlook

harvest from indium run in 2003

- more than 100 000 reconstructed J/ψ events (before track matching)
- ~ 1 million signal low mass dimuons (after track matching)
- mass resolution ~ 25 MeV at the φ
- signal to background ratio around 1:1 or 1:2 depending on collision centrality (a factor 4 better than before muon track matching)

proton run in 2004

~ 70 days of 400 GeV protons, 7 different targets, high beam intensities (~ 2×10^9 p/burst)

- reference for the heavy-ion data
- impact of χ_c production on the J/ψ suppression
- nuclear dependence of open charm production
- intermediate mass prompt dimuons
- low mass dimuons with unprecedented accuracy

proton and ion data together

- study the **low mass region**, including the ρ, ω, φ resonances
- identify the origin of the **excess of intermediate mass dimuons**
- improve the understanding of the **production and suppresion of the charmonium** states

- nuclear dependence of charm production and prompt Drell-Yan dimuons
- look for the $D_0 \rightarrow \mu^+\mu^-$ rare decay

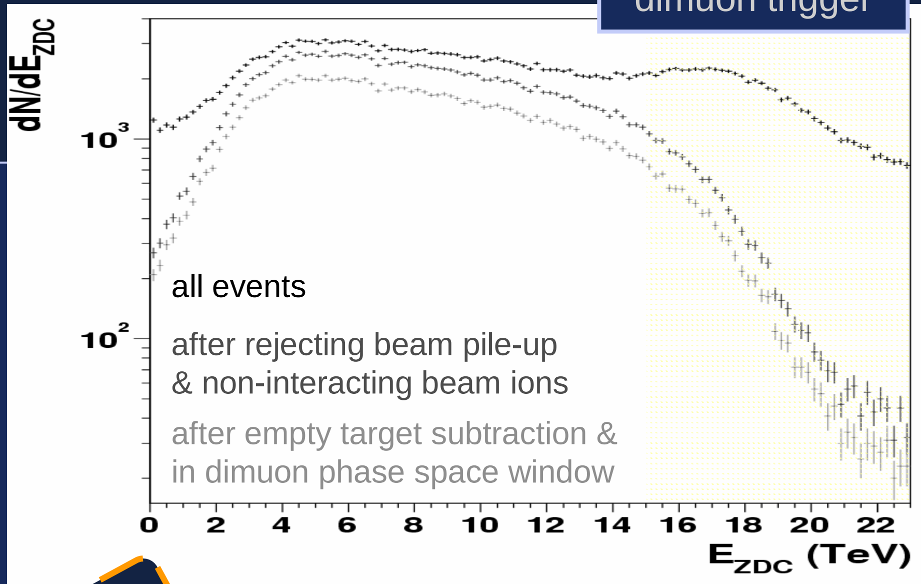
In '2003 – ZDC

ZDC forward energy spectrum

- dimuon trigger
- minimum bias (ZDC) trigger

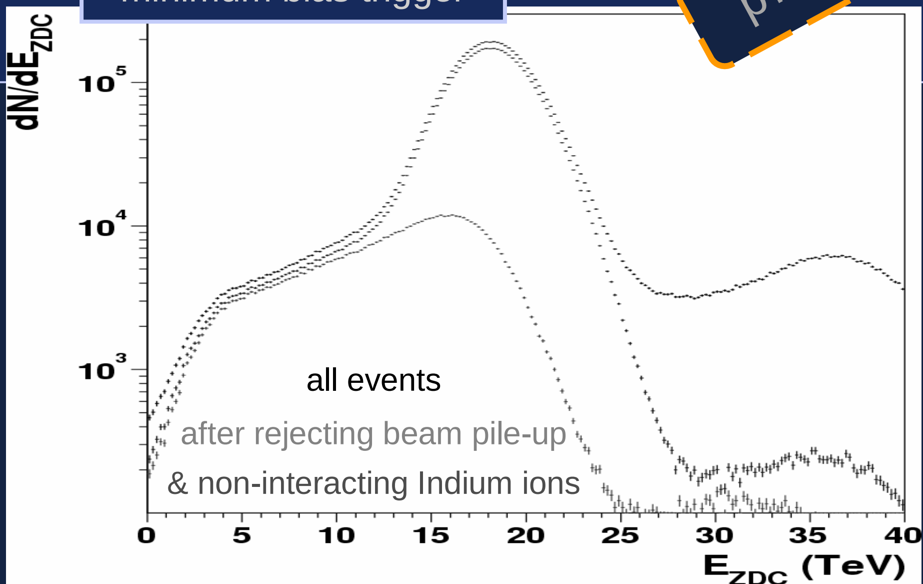
- beam pileup rejected by the Beam Tracker
- non-interacting ions rejected by the Interaction Counter
- severe quality cuts

dimuon trigger

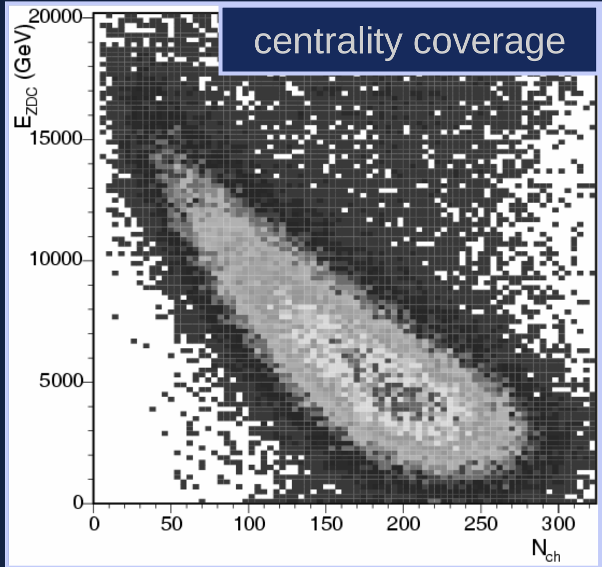


preliminary

minimum bias trigger



centrality coverage



ZDC forward energy vs. multiplicity from Pixel Tracker